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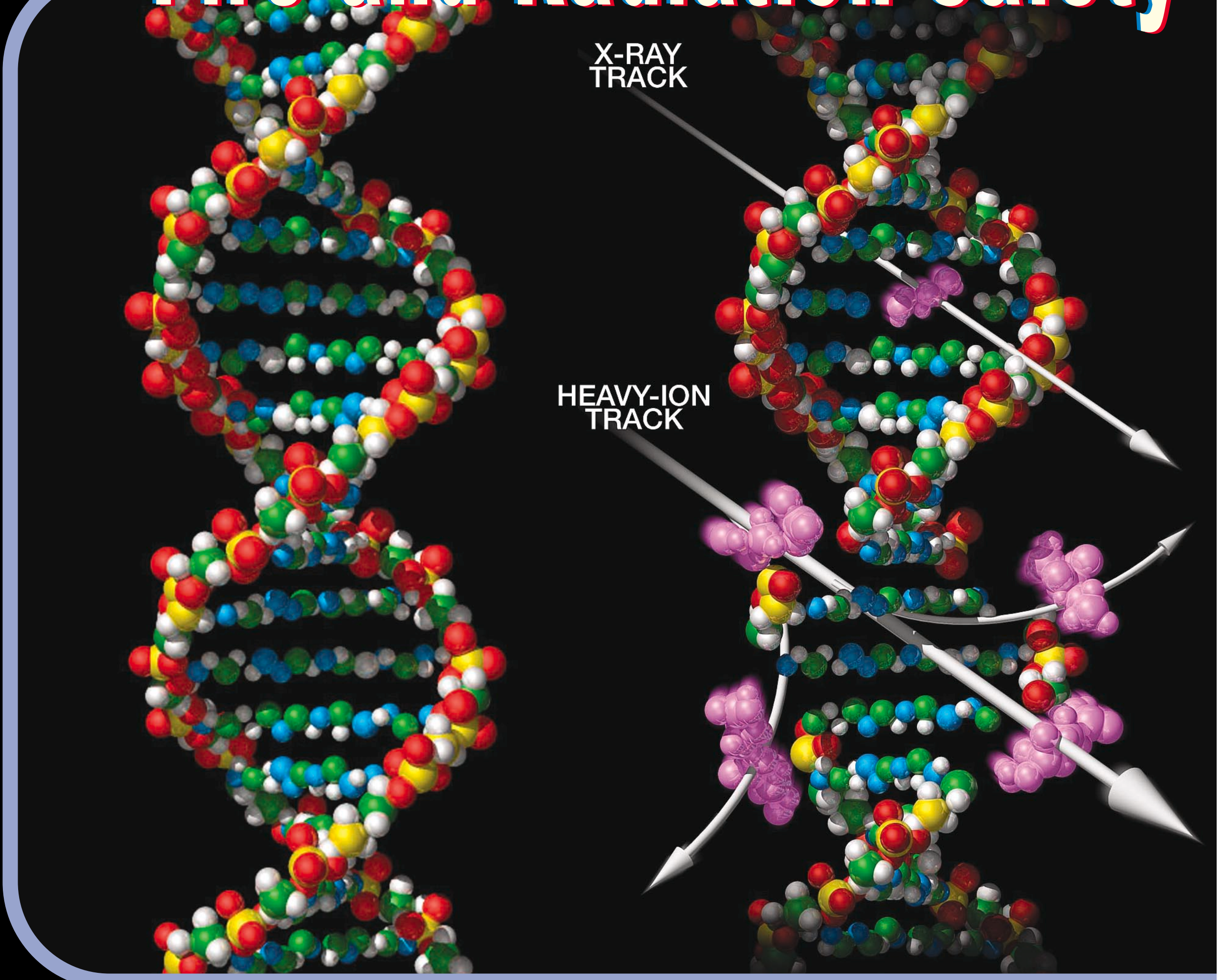
Space Research

Office of Biological and Physical Research Vol. 1 No. 1

Fire and Radiation Safety



Profile:
Peggy
Whitson

National Aeronautics and
Space Administration

Letter From the Associate Administrator

Welcome to the inaugural edition of the *Space Research* newsletter and to NASA's newest enterprise, the Office of Biological and Physical Research. This enterprise was established as a catalyst for space research in support of the biology revolution of the 21st century. Our goal is to foster research advances in biotechnology, biomedicine, commercial development, and the physical sciences. This newsletter will inform you about such research advances.

The charter of our enterprise contains exciting goals: to conduct research that will enable safe and productive human habitation of space; to use microgravity as a laboratory for testing fundamental principles in physics, chemistry, and biology; to promote private-sector investment in space; to support academic achievement in the sciences; and to improve the quality of life on Earth. As we pursue these goals, we will foster collaboration and build on the natural synergy among our research disciplines.

We are also a part of NASA's overall mandate to bring the experience of space and space research to the public. For those familiar with the content of *Microgravity News*, much of the format will be retained in this new version. *Space Research* will build on the success of *Microgravity News* to encompass an expanded scope that reflects the more comprehensive vision of the Office of Biological and Physical Research. In this inaugural edition, and in the ones to follow, we will cover both broad and more narrowly defined topics. Feature stories will draw upon a common theme among several research disciplines, such as radiation and fire safety in space, covered in the feature article in this issue. Research updates will explore widely diverse topics, such as cardiovascular, nervous system, and muscle changes arising from extended exposure to microgravity; gene, cellular function, and evolutionary biology research under microgravity conditions; the physics of condensed matter, fluids, biomolecules, and combustion; and commercial research to improve antibiotic production rates, fuel refining and combustion processes, and sensor technology for early detection of skin disease. Profiles will cover researchers who are making significant contributions in their respective fields.

Space Research articles also may reflect challenges we face as an enterprise. The Office of Biological and Physical Research will assume program and fiscal responsibility in the coming calendar year for research conducted on the International Space Station (ISS). We must therefore strike an effective balance by attaining and sustaining an ongoing research presence in microgravity while maintaining a strong ground-based research program. We must also maintain an equitable balance in our research disciplines, supporting diverse initiatives while ensuring an overall cohesion and clarity of focus to make the greatest use of the resources at hand on the ground and in space.

We must build on our support for education and outreach, given NASA's unique position among federal agencies to fire the imagination of today's youth, particularly in the fields of math and science, and given the agency's mandate to disseminate the experiences of space and space research to broad sectors of the public. We will meet these challenges.

We are poised to play a key role in the ISS as it becomes an on-orbit, ongoing laboratory pushing the boundaries of knowledge in the life and physical sciences, fostering commercial research, and benefiting life on Earth. In a very real sense, we will be the "heart" of the ISS.

We hope you enjoy *Space Research*. Those of you who were readers of *Microgravity News*, thank you for your continued interest. To our new readers, thank you for joining us. We want this newsletter to reflect the interests of our readers, and we welcome your thoughts. Send your comments to John Emond; e-mail: *john.emond@hq.nasa.gov*; phone: (202) 358-1686. Please visit our web site at *http://spaceresearch.nasa.gov/*.

Kathie L. Olsen

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Acting Associate Administrator
Office of Biological and Physical Research

On the cover:
Radiation (right) is a significant hazard in space flight. Finding ways to provide protection from increased radiation exposure in space is one of NASA's top priorities.
Credit: Frank Cucinotta, Johnson Space Center, and Prem Saganti, Lockheed Martin

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Hampton University Microgravity Outreach Project

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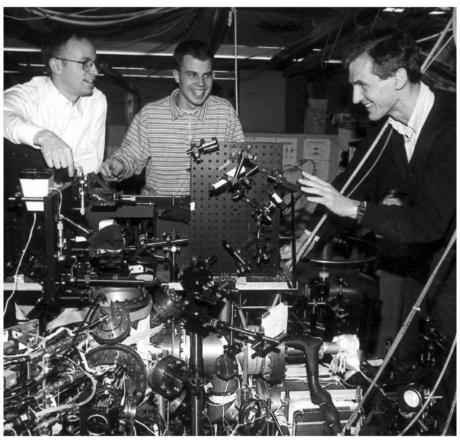
Ketterle Receives Nobel Prize

Principal Investigator Wolfgang Ketterle has been awarded the 2001 Nobel Prize for physics for his NASA-funded research involving ultra-cold atoms that form a new type of matter. The Massachusetts Institute of Technology (MIT) physicist shares this year's prize with Eric Cornell and Carl Wieman, both of the Joint Institute of Laboratory Astrophysics and the National Institute of Standards and Technology, Boulder, Colorado.



credit: Donna Coveney

Ketterle (right) and former physics graduate students of his discuss the machine they and their MIT collaborators used to demonstrate the first atom laser.

The award cites the researchers' achievements and early fundamental studies of Bose-Einstein condensates, a peculiar form of matter predicted by Albert Einstein, based on research by the Indian physicist Satyendra Nath Bose. The Royal Swedish Academy of Sciences, which awards the honor, said the three scientists have caused atoms to "sing in unison." Through their research, atomic particles were induced to have the same energy and to oscillate together in a controlled fashion. Laser light has these qualities, but researchers have struggled for decades to make other matter behave this way. The breakthrough research has potential uses for extremely precise measurements and may lead to microscopic computers and ultra-precise gyroscopes that could dramatically improve aircraft guidance and spacecraft navigation.

More information on Ketterle's research and images of his work are available on the Internet at *http://cua.mit.edu/ketterle_group/home.htm*. More information on Nobel Prizes for physics from 1901–2001 is available at *http://www.slac.stanford.edu/library/nobel.html*.

NASA Honors Terrorist Act Victims

On September 11, NASA was witness to evil. With the launch of space shuttle *Endeavour* on flight STS-108, NASA remembers those lost that day and pays tribute to courage.

According to an October 11 article in *The Washington Post*, ISS commander Frank Culbertson and cosmonauts Vladimir Dezhurov and Mikhail Tyurin were performing their duties on September 11 at 10 a.m. Eastern Standard Time when a Houston flight surgeon radioed word of the terrorist attacks on the World Trade Center and the Pentagon. Culbertson noted a computer display and saw the ISS was passing above Canada on its way toward New England. Culbertson looked out a porthole; even at a track that was far north of New York and 240 miles above Earth, the plume of smoke and ash rising from the tip of Manhattan was clearly seen. One orbit later, the station crew looked toward Washington, D.C., and saw a smoky haze from the attack on the Pentagon.

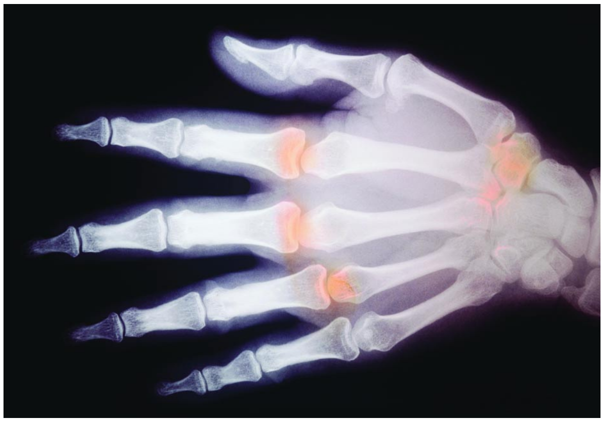
Although the smoke is no longer visible from the ISS, NASA wants to reflect on the human and emotional sacrifice connected to the terrorist acts of September 11. As the *Endeavour* delivers the fourth crew to the International Space Station, it carries a special and symbolic cargo: nearly 6,000 United States flags. When the flags are returned to Earth, they will be presented to the families of the victims of the attacks in New York and Virginia, to the families of those killed aboard United Airlines flight 93, which crashed in a field in Pennsylvania, and to the families of the heroic men and women who rushed to the aid of the stricken and became victims themselves.

As part of this "Flags for Heroes and Families" campaign, NASA administrator Daniel S. Goldin presented to New York City Mayor Rudolph Guiliani an American flag that flew on a previous shuttle flight. In addition, NASA plans to present flags to the New York firehouses and police precincts that participated in the rescue and recovery efforts. The flag campaign, initiated in part by the Office of Biological and Physical Research, is also a way for NASA to honor the thousands of people around the world who have selflessly contributed to the relief and recovery efforts that have taken place since the September 11 attacks.

As Culbertson was quoted in the *Post* as saying about the ISS and peaceful endeavors: "I hope the example of cooperation and trust this spacecraft and all the people in the program demonstrate daily will someday inspire the rest of the world to work the same way. They must!"

“Good Vibrations” May Prevent Bone Loss in Space

New physiology research suggests the vibration of bones may help astronauts stay healthier during long spaceflights and could help people suffering from bone loss here on Earth. Principal Investigator Clinton Rubin, of the State University of New York at Stony Brook, has discovered that barely perceptible vibrations may halt bone loss and stimulate new bone growth. Loss of bone mass is one of the primary medical effects of spaceflight, and this research could be very useful in counteracting those effects. It also has the potential for helping those on Earth who suffer from osteoporosis or who have been immobilized by paralysis or bed rest.



Bone loss during space flight has long been a concern for astronauts. Recent physiology research shows that subjecting bones to slight vibrations may help prevent such bone loss and could stimulate new bone growth.

Although researchers do not fully understand the physiological mechanism at work, the vibrations appear to fool the bones into thinking they are working hard. The bones interpret this as “stress” and respond by trying to increase strength by maintaining and sometimes adding bone tissue. This is important for space research because the absence of mechanical stimulation in microgravity leads to substantial bone loss and muscle weakness in astronauts. In flights lasting from four to six months, astronauts can lose bone mineral density approaching 1.6 percent per month. Extrapolating from current research, scientists estimate that during a two-and-a-half-year round-trip mission to Mars, astronauts could lose up to half of their bone density from specific parts of the skeleton. Such a loss could seriously jeopardize an astronaut’s health on return to Earth.

At the same time, current astronaut exercise regimes for long-duration space missions are time consuming, eating away at valuable crew time. Low-level vibrations may offer a solution to this problem that will both save time and be more effective than current medical treatments or exercise regimes.

For more information on this research, visit *http://www.nasa.gov/releases/2001/01-187.html*

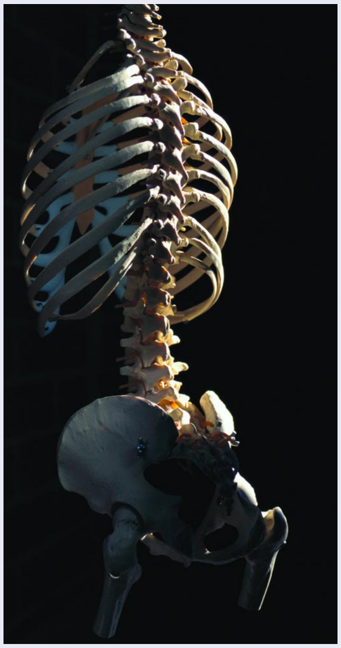
Porous Ceramics for Bone Replacement

Principal Investigators John Moore and Frank Schowengerdt of the Center for Commercial Applications of Combustion in Space at the Colorado School of Mines, Golden, Colorado, along with Sulzer Orthopedics Biologics and other companies, have developed a ceramic-metal composite that may lead to better bone replacements.

This composite, synthesized by a process known as self-propagating high-temperature synthesis (SHS), is very porous. Its total porosity, pore size distribution, and ratio of open to closed pores make it more compatible with natural bone than current bone implants. The composite’s unique porous structure allows blood vessels, nerves, and even natural bone to grow through and around the composite, thereby greatly increasing its effectiveness as a bone replacement.

The bone-replacement materials currently in use all have problems associated with them: they are expensive, are incompatible with bone growth, may potentially carry pathogens, or are simply not strong enough. Composites created under microgravity conditions exhibit dramatic differences from those created under normal gravity. The pore properties of the composite can be tailored to match those of natural bone, thereby mitigating some of the problems associated with traditional bone implant materials.

Development of a porous ceramic composite with potential as a bone replacement material is continuing at the Center for Commercial Applications of Combustion in Space at the Colorado School of Mines.



Experiments on porous ceramics have been performed under microgravity conditions for years using NASA’s KC-135 aircraft and will be continued aboard the International Space Station. Knowledge gained from these experiments will be brought back to Earth and used to develop better and more cost-effective processes for producing ceramic composites.

For more information on this project, visit *http://www.mines.edu/research /ccacs/Porous_Ceramics/Porous_Ceramics.html*.

Fire and Radiation Safety Get New Emphasis From

NASA's mission success starts with safety.

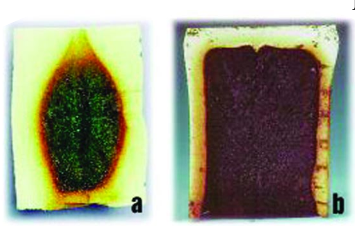
Credit: U.S.Navy photo by Photographer's Mate 1st class Michael Worner.

A Navy fire-fighting instructor leads firefighters in battling a Class Bravo (oil-fed) fire during a military training session. Both NASA and the military put great emphasis on being prepared for various fire hazards, either on Earth or in space.

As crews from the United States and its partners assemble the International Space Station (ISS), the casual observer may miss an underlying emphasis on safety that makes the work sometimes appear effortless.

"Safety is NASA's number-one core value," says Kristen Erickson, deputy associate administrator for management in the Office of Biological and Physical Research (OBPR), NASA's newest enterprise. "One of the things we are trying to instill is that safety has to be a state of mind. You can't just put up a bunch of posters." Erickson previously was head of the space shuttle's budget office and program evaluation, where flight safety had the highest importance, "so you can see why I'm such a zealot," she explains.

While the general public may be concerned about safety in space only after an accident or a catastrophe, NASA has ongoing commitments to ensure that vital equipment does not fail on the ground or in flight and to reduce occupational hazards for ground and flight crews. Supporting research on in-orbit fire prevention, detection, and extinction and on the effects of space radiation and shielding is one way NASA meets these commitments. Fire and radiation safety are linked by a common need: to further our understanding of basic science and use it to develop advanced materials. Fire is a violent chemical reaction, as oxygen combines with other materials to produce smoke, heat, and deadly chemicals. Radiation involves high-energy particles (as well as X-rays and gamma rays) that can have devastating, even deadly, effects on living beings. NASA wants to apply the results of research in basic and applied science to reduce the hazards from each. But first, scientists must understand and fully define the fire and radiation problems, and then they must tackle new designs to mitigate or eliminate them. OBPR will play a key role in doing both.



credit: NASA

Research has shown that the way a material such as polyurethane foam burns in regular gravity and air (a) is no indication of how it will react in microgravity and an atmosphere of enriched oxygen (b).

"One thing we expect to invest further in is research on space radiation and its potential impact on humans," Erickson continues. She also expects that in addition to making space travel safer, the fire and radiation studies will find beneficial applications on Earth.

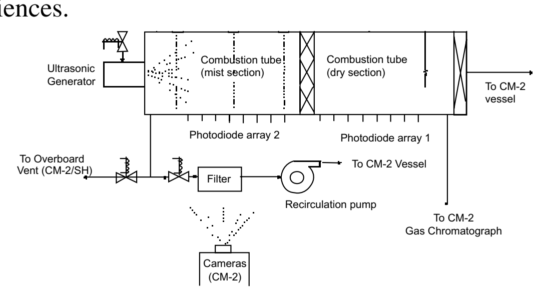
Fire

Until recently, most of OBPR's interest in fire was in using microgravity as a research lab for insight that might improve combustion systems on Earth. While this remains a highly valuable line of work, OBPR has new emphases on studying how fires start and propagate in microgravity and how they can be extinguished quickly and safely. The subject is far more complex and subtle than campers pouring water on the fire until the flames and sparks disappear.

To grapple with the challenge, NASA held a workshop dedicated solely to spacecraft flammability issues at Glenn Research Center (GRC), NASA's lead center for microgravity combustion research, in June 2001. Participants at this first workshop of its kind in 15 years included representatives from the National Institute of Standards and Technology, the Naval Research Laboratory, Sandia National Laboratories, and universities, as well as from NASA. Attendees addressed fire prevention and materials flammability, smoke and fire detection, and fire and postfire response. "We wanted to assess the state of the art of spacecraft fire safety, determine the knowns and unknowns, and identify specific research needs," said Gary Ruff, of GRC, who chaired the workshop.

The first, most important step that can be taken, whenever possible, in fire safety is to select materials that don't burn easily in low gravity. NASA's Marshall Space Flight Center has a Materials Combustion Research Facility that tests materials against a range of industry and NASA standards. Because it is impossible to eliminate all combustible materials, such as the paper on which flight plans and procedures are written or the plastics that are used in almost everything, steps also must be taken to ensure that a fire can be detected and extinguished while protecting the crew and equipment. ISS fire detectors, developed through experiments sponsored by OBPR's Physical Sciences Division and conducted on the shuttle, look for smoke particles sparkling in a laser beam. To fight fires, the crew is supplied with portable fire extinguishers (which dispense carbon dioxide) and portable breathing apparatus. NASA wants a nontoxic suppressant that does not foul the life support system or require extensive cleanup. The workshop recommended conducting microgravity experiments, in addition to continuing those in ground-based facilities, on items likely to burn in space. Research is also needed in computational flow dynamics to understand where a fire goes inside a compartment in microgravity, how fire-fighting agents are transported, and how the agents interact with the air and fuel.

"One thing that came out of the workshop was a new roadmap for spacecraft fire safety research," Ruff says. "After the workshop, we revisited our existing research projects and plans to make sure we didn't miss anything and shift some priorities. It really helped us define and focus our current research better." The results of the workshop are refocusing existing projects and will affect future NASA Research Announcements (NRAs) with regard to combustion sciences.



Credit: Colorado School of Mines.

A schematic diagram of the apparatus for the Water Mist project.

In the past, several shuttle missions carried experiments to examine the microscale physics and chemistry of combustion under low-gravity conditions, where convective flow is nearly eliminated, clarifying the view of what is happening. The ISS is expected to host a broader range of combustion experiments over the next 10 to 15 years. Attention now is shifting to understanding the physics and chemistry of putting out fires for applications on Earth as well as in orbit. The space shuttle's Research-1 mission (STS-107, scheduled for launch in 2002) will take the first step in this new direction with the Water Mist experiment.

"We are trying to understand the fundamentals," says Frank Schowengerdt, director of the Center for Commercial Applications of Combustion in Space (CCACS), a NASA commercial space center located at the Colorado School of Mines. "We want to understand how fire extinction depends on water particle size, water concentration, droplet distribution, and radiation from the fire." The CCACS is part of OBPR's Space Product Development program. Water Mist is a different approach for the center, since the CCACS was established to develop improved combustion technologies, not to study how to stop fires.

"When we first set up this center, Tom [McKinnon, a CCACS chemical engineer,] said he had always puzzled over just exactly how water puts out a fire," says Schowengerdt. "Five years ago, he wasn't taken seriously. Another federal agency said they did some research three to four years ago and gave up. But they did it the wrong way, through crude trial and error." McKinnon persisted and developed more analytical experiments and models. He is now the principal investigator for Water Mist. "Without doing the fundamental science you don't make advances," Schowengerdt continues. "You

Credit: CCACS

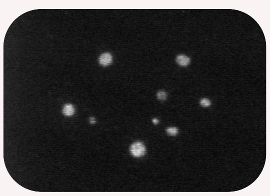
This sequence of photos shows a standard fire suppression test of the EEC Water Mist System at the Fire Training and Research Center in Arvada, Colorado. A clearly visible cloud of mist descends over the flames, putting out the fire quickly and efficiently. The effects of different water droplet sizes and concentrations are tested to determine the optimal parameters of the system.

Fire in Space

The extreme reduction of buoyancy in the microgravity environment of orbit means a fire's hot products no longer rise, and cold air no longer sweeps in to take their place, thus sharply reducing the magnitude of the fire. The image of a space candle surrounded by a ghostly blue sphere as exhaust products diffuse outward and fresh oxygen diffuses inward is the best-known result of a long series of space combustion experiments conducted aboard U.S. space shuttles and Russia's *Mir* space station. Such studies promise to let scientists and engineers fine-tune the design of engines so that they burn fuel more efficiently and produce fewer toxic by-products.

Several discoveries about the physics of combustion have been made in recent NASA experiments. The Fiber-Supported Droplet Combustion experiment on the Microgravity Science Laboratory-1 (MSL–1) showed two droplets pushed apart by their exhaust gases, then drawn together as oxygen was depleted between the drops and combustion faded on the facing sides of the droplets.

Also on MSL–1, the Structure of Flame Balls at Low Lewis-number (SOFBALL), investigated small fireballs that form when a spark arcs through a lean fuel-air mixture. Although they are the weakest known flames (only 1 watt thermal), they usually lasted for minutes, often longer than the experiment runtime. The implication for fire safety is that fuel gases in a spacecraft could be ignited and drift across a cabin, undetected, for several minutes. Space testing of some materials, such as plastics widely used in flight hardware, has started, as described in "Flammability Results from *Mir*," in the Spring 2000 issue of *Microgravity News* and "Revolution in the Making," in the Winter 1998 issue.



credit: NASA

The Structure of Flame Balls at Low Lewis-number (SOFBALL) investigates small fireballs that can ignite in the lean fuel-air mixture inside spacecraft. While weak (1 watt versus 50 watts for a birthday candle), they can last for several minutes and are very difficult to detect. The fireballs in the picture are visible only because they were captured in the dark by cameras with image intensifiers.

might get lucky in a trial-and-error approach, but you might spend a lot of money on it."

Schowengerdt and his colleagues want to know the absolute minimum required to put a fire out so the cleanup is easier, postfire damage is reduced, and flight crews are exposed to fewer toxic by-products. Scientists are returning to water as the ideal suppressant.

Water droplets have more surface area than a stream of the same volume straight out of a hose. Droplets can absorb more heat and coat more fuel. But exact details of the physics and chemistry remain elusive, largely because the reactions happen so quickly in Earth's gravity. Droplets settle, so a controlled, uniform cloud of them can't be maintained to see what happens when the flame interacts with them. In microgravity, the drops remain suspended, so a better experiment can be conducted. Therefore, McKinnon looked to orbit, where experiments can run slower and with less turbulence. Scientists can thus focus on a narrower range of variables and study them over an extended period of time.

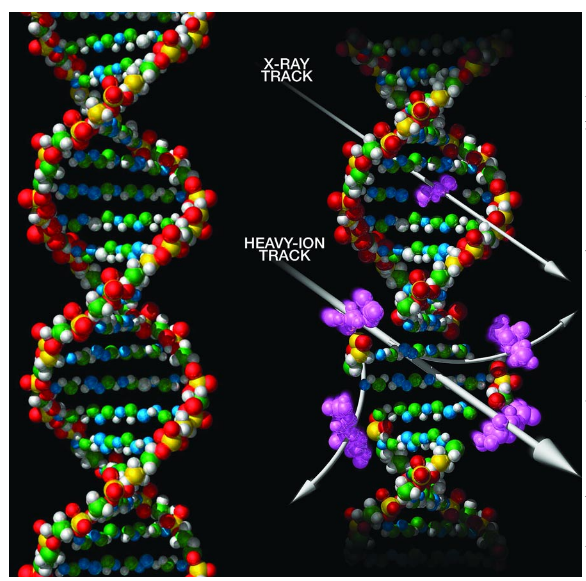
The CCACS has conducted extensive tests on the ground, including some at a drop tower facility at the School of Mines. Now it is time to move upward, literally. "We're looking at a lot of different things that we can do far better in microgravity," Schowengerdt explains.

Water Mist will employ a small nozzle to spray water into a chamber through which the flame will move. "We're not talking here about sprinkler systems that everyone has," Schowengerdt says. Because a high-pressure water line would be difficult to set up in the confines of the experiment module, ultrasonics break the water into droplets about 10 microns in diameter. "You probably couldn't use that in a real situation, because high pressures are needed," says Schowengerdt. For fundamental experiments, though, the mist should be sufficient. From this, scientists could start to develop methods to optimize water sprays for different types of fires. The CCACS also is looking at additives that would keep the water from conducting electricity. Following STS-107, Schowengerdt hopes to do extended experiments aboard the ISS.

The CCACS's work is getting attention from potential terrestrial users, including the Federal Aviation Administration, the U.S. Navy, computer system operators, and even restaurants. NASA also is interested in Water Mist as part of a larger investigation into fire safety aboard spacecraft.

Radiation

The latest NRA is looking at protection from one of the earliest-known space hazards. Radiation brings a different set of complexities and subtleties to the problem of protecting crews. "Empty" space is heavily traveled by radiation that can sicken or kill any known life-form. While ISS crews are relatively shielded by

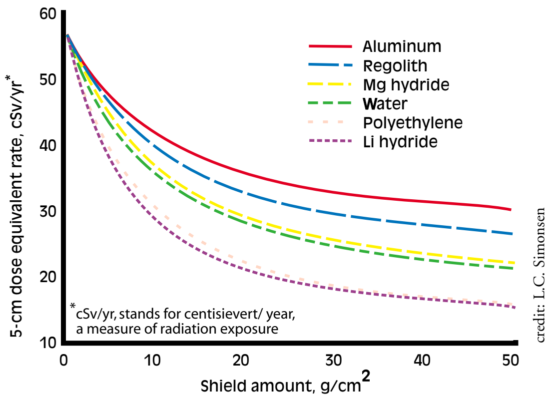


Credit: Frank Cucinotta, Johnson Space Center, and Prem Saganti, Lockheed Martin

The blueprint of life, DNA's double helix (left), is found in the cells of everything from bacteria to astronauts. Exposure to radiation (right) can change or disrupt the polymer strands of nucleotides joined together, causing dire consequences both to the organism itself and to its future generations.

Earth's magnetosphere, they are more exposed than people living at sea level beneath Earth's cushion of air. Crews that travel to Mars will be exposed far longer than the Apollo crews going to the Moon — years instead of days. The agency also wants radiation issues addressed openly by managers and astronauts alike: "We are very much concerned that the acceptance of risk is an important ethical issue that gets revisited continuously," Erickson says.

Like fire safety in space, OBPR is working simultaneously to define the problem in full even as it works on possible solutions. Its Strategic Program Plan for Space Radiation Research outlines a comprehensive approach to develop these solutions. In addition, NASA works closely with the National Research Council of the National Academy of Sciences and with the National Council on Radiation Protection and Measurements to maintain updated guidelines from the scientific and radiation protection communities.



Materials with smaller mean atomic mass, such as lithium (Li) hydride, make the best shields for astronauts. The materials have a higher density of nuclei and are better able to block incoming radiation. Also, they tend to produce fewer and less dangerous secondary particles after impact with incoming radiation.

From an enterprise perspective, radiation protection is truly a cross-disciplinary, cross-division problem that touches life sciences, space biology, and the physical sciences. To systematically study the biological effects of space radiation, NASA has been developing a new ground-based space radiation simulation facility, the Booster Applications Facility. The facility, which is expected to be commissioned in 2003, is being built in collaboration with the Department of Energy and will utilize high-energy accelerators at Brookhaven National Laboratory. When the facility is fully operational, atoms of various elements will be stripped of their electrons and accelerated to high velocity to produce the full range of particles and energies that are present in space.

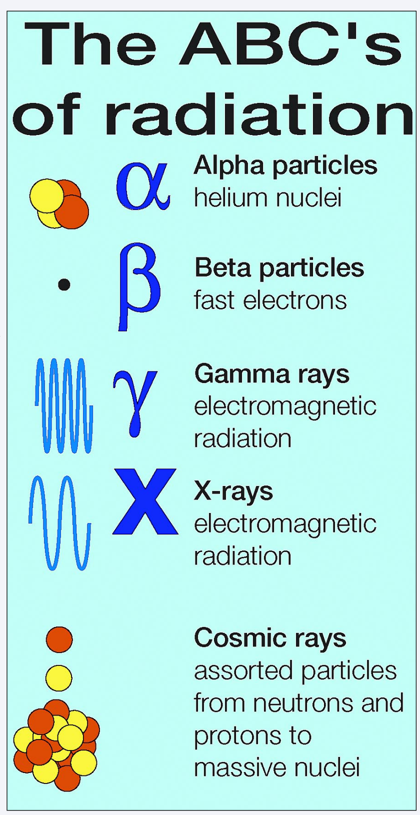
Ground-based studies in already-existing facilities have shown that the effects of space radiation are significantly different from the effects of X-rays and other radiation types common on Earth. The high-energy charged particles of space radiation, threading through a coiled DNA molecule, can easily break it in more than one place. A study of the size of the broken pieces has led to a new understanding of how DNA

The ABCs — and Xs and Zs — of Radiation

Alpha and beta rays are particles. Gamma rays are electromagnetic radiation, like X-rays but at higher energies. Health physicists worry most about HZE cosmic rays, those with high mass (Z stands for atomic number, which also implies mass) and energy (E). They have two principal sources, the Sun and the galaxy.

Solar Energetic Particles (SEPs) are largely high-energy protons, naked hydrogen nuclei. Radiation from a solar flare can be debilitating or even fatal in an unshielded exposure. Galactic cosmic rays (GCRs) come in a wide variety of naked atomic nuclei spewed from supernovas or from dust pummeled by older cosmic rays. Most are made of light-weight stuff, about 85 percent hydrogen (Z=1) and 14 percent helium (Z=2) nuclei. The remaining 1 percent are mostly heavier, stable elements. The heaviest element that is sufficiently abundant to be of concern for radiation protection is iron (mass around 56), although traces of all stable elements have been observed in GCRs. The median velocity of the GCRs is approximately 95 percent of the speed of light (corresponding to the velocity of a proton with an energy of 2000 MeV). The radiation content changes with the solar cycle. At sunspot maximum, the expanded heliosphere moderates GCRs, but emits more SEPs.

Like a bullet fired through a cinderblock wall, a cosmic ray hitting metal shatters the target nucleus and is itself shattered. Although the total energy remains the same, the interaction showers secondary and tertiary particles, some of which produce gamma rays. All in all, it is a messy business.



winds itself up for storage in the cell. Another way in which space radiation can be seen to be different is by enhanced "genomic instability," a result of irradiating living cells that leads some of the dividing daughter cells, as many as 10 or 20 divisions later, to change in the direction of becoming cancer cells, at a rate much greater than the control cells.

Because of these and other dangers to human space travelers, radiation in space must be avoided as much as possible. At present, exposure to radiation is reduced in one of two ways: the use of "shielding" materials interposed between humans and the external radiation to attenuate its intensity, and careful timing of space activities to coincide with times when radiation is least intense.

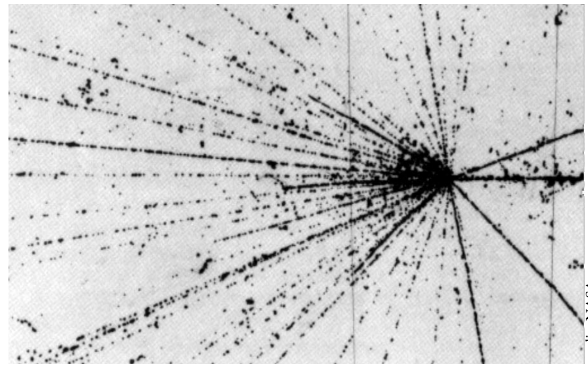
To build a better shield, NASA must understand fully what happens when radiation strikes different materials, including flesh. (See sidebar titled "The ABCs — and Xs and Zs — of Radiation.") "We need to know the interaction with a spacecraft and its shields, and also what happens after particles get through something," says Michael Wargo, materials science discipline scientist of OBPR's Physical Sciences Division. "Materials science is responsible for [addressing] one part of the problem. We are approaching on two fronts. We need models and computer programs to predict. And we need experiments to validate and to improve models and programs."

A workshop at Lawrence Berkeley National Laboratory (LBNL) in 2000 developed a roadmap to plan a tractable solution to the problem. Its findings are incorporated in "Materials Science: Ground-Based Research Opportunities in Biomaterials and Radiation Shielding" (NRA-01-OBPR-05), released August 24, 2001.

"There are three things we need to know," says Walter Schimmerling, of NASA headquarters, who developed the strategic plan and is a principal author of the roadmap. "First, we need to be able to predict the risks, like possible health effects, that are likely to occur and the percentage of the time that they will occur. Second, we must reduce the uncertainty of risk. We need precise predictions. Third, we have to moderate the risk."

Radiation protection will involve a series of steps, not a single solution. "One way [to limit the risk of effects from radiation] is by timing the exposure," explains Schimmerling. For example, extravehicular activity is scheduled to avoid passages through the South Atlantic Anomaly, a low-altitude portion of the Van Allen Radiation Belts over the coast of Brazil, where radiation is more prevalent than in other sections of Earth orbit.

"Next, you can reduce the amount of radiation that gets to people," Schimmerling continues. That


credit: NASA

Certain types of radiation are dangerous to the body because they collide into cells with an effect similar to the above image of a debris trail left by an iron nucleus slamming through plastic. The impact breaks up the incident particle into smaller particles that can then penetrate and damage the cell and surrounding tissue.

means introducing materials that interpose their atoms between the crew and the outside. Atoms are largely empty space, with electrons spinning around a nucleus like remote planets circling a sun. Incoming cosmic rays will be slowed down by friction with the electrons and, every once in a while, they may hit a nucleus, although there is plenty of room for cosmic rays to miss "solid" matter.

Ideally, one would like all the incoming cosmic rays to lose so much energy in the shielding material that they stop inside of it. Unfortunately, the amount of material required to stop the lightest and fastest particles — their "range" — requires an amount of material much greater than anything that can be carried on a spacecraft. In addition, the heavier cosmic rays that do collide tend to break up into lighter pieces with the same velocity and, therefore, with greater "range."

Still, biologically, slowing down some types of cosmic rays makes them more damaging, so it is preferable to have these collisions. Conversely, slowing down the heaviest cosmic rays sometimes results in less biological damage. Thus, the evaluation of shielding effectiveness is a complex issue that depends very much on the actual composition of the radiation. Schimmerling credits NASA's Langley Research Center for work in the late 1980s on radiation transport calculations that showed that materials that contain a high proportion of hydrogen make the best shields. One of the most practical materials is polyethylene, a polymer chain of carbon atoms, each connected to two hydrogen atoms — the stuff plastic grocery bags and kitchen cutting boards are made of.

The most important areas of a spacecraft to shield are the crew quarters, galley, and other areas where the crew spends a third or more of their time. (See sidebar titled "The Christmas Radiation Brick.") "But you can't block everything," Schimmerling continues. "After 40 or 50 percent you reach the point of diminishing returns." If a thickness of shielding reduces radiation intensity by one-half, adding the same amount only reduces the remaining radiation by one-half of one-half, or one-fourth. The third layer only contributes one-eighth the protection, and so on. Therefore, the next level of protection is to understand what happens at the biological level when radiation passes through a cell and determine how to help the body's natural repair systems. "In the long run, we are trying to provide some biomedical intervention," Schimmerling says.

"Complicating the exposure issue is the fact that not all people react equally to the same dosage," says Francis Cucinotta, of Johnson Space Center's Life Sciences Directorate. "Younger people are more susceptible to damage because they have more years left for damage to develop, and their cells are still more actively dividing to replace themselves. Women are at greater risk for radiation-induced cancer because they have two radiation-sensitive organs (breasts and ovaries), and a longer expected lifespan."

As the revolution in the understanding of biology continues, it is clear that, eventually, ways will be found to improve the ability of damaged cells in human bodies to repair themselves, to help the body to rid itself of cells too damaged to be repaired, to understand the differences between individuals that make some less resistant to radiation than others, and to develop tools to diagnose changes, such as the ones that lead to cancer, much earlier, when the chances of successful treatment are vastly better.

In the meantime, quantifying the risks and actual exposures better will allow NASA managers to determine how many missions an individual can safely make. "What we would like to do in clear terms is be able to assess within an appropriate margin of safety, so every astronaut can have three 180-day missions on the ISS," Schimmerling says. That level could be achieved by older males now, but NASA wants to be able to offer equal mission opportunities to all astronauts. In addition to the all-important safety of NASA crews, being able to assure longer, multiple missions can help NASA realize substantial savings by allowing for the scheduling of fewer crew replacement missions and limiting the size of the astronaut corps that needs to be maintained. Career limits are also likely to be an important issue for astronauts, whose hard-won experience cannot currently be utilized for more than one or two ISS missions.

Schimmerling expects that the current revolution in biology will allow significant advances. "Can you give people a medicine to inspect and repair cells?" he asks. "There are mechanisms in the body that do this already. We just don't know how they work or how to harness them to undo radiation damage." But given time and research — radiobiology research in the Bioastronautics Research Division and materials research in the Physical Sciences Division — OBPR scientists hope to find the answer.

Dave Dooling

For more information on fire safety research in space, look up *http://microgravity.grc.nasa.gov/combustion/index.htm#top*. A copy of "Materials Science: Ground-Based Research Opportunities in Biomaterials and Radiation Shielding" (NRA-01-OBPR-05), which includes the roadmap to solving space radiation problems, is available at *http://research.hq.nasa.gov/ code_u/nra/current/NRA-01-OBPR-05/ index.html*. Questions for Gary Ruff should be directed to *Gary.A.Ruff@grc.nasa.gov*; for Michael Wargo, *michael@microgravity. msad.hq.nasa.gov*; for Walter Schimmerling, *wschimme@mail.hq.nasa.gov*; for Francis Cucinotta, *francis.a.cucinotta1@jsc.nasa.gov*. For more information on the CCACS, go to *http://www.mines.edu/research/CCACS/*.

The Christmas Radiation Brick

While most kids try to avoid getting a lump of coal in their Christmas stockings, astronaut Susan Helms, a member of the ISS Increment 2 crew, got a brick. This was the Christmas Radiation Brick, a truly American gift, devised by an engineer in his garage applying the results of 20 years of research into nuclear physics and shielding calculations for actual shielding use. The results of this work predicted that one of the best shielding materials would be polyethylene.

Francis Cucinotta, of Johnson Space Center's (JSC's) Life Sciences Directorate, credits JSC's Mark McDaniel with developing a quick, effective way to give Helms extra shielding in her temporary sleep station. "In his garage, he came up with this concept of blocks," explains Cucinotta. "It's just polyethylene — CH_2. For fire protection, it's wrapped two times in aluminum tape and Nomex [flame-retardant fabric]." The delivered unit, assembled in JSC clean rooms, costs less than $100,000.

Helms' temporary sleep station was an empty rack position in the Destiny lab module. The shielding was wrapped up as a 150-pound "brick" for launch, then unfolded in orbit to provide shielding on three sides. Air ventilation and crew egress requirements restrict how much of the sleep area can be enclosed. Cucinotta says NASA is negotiating with the Russian Space Agency to add shielding to the sleep stations in the Zarya module, and with the Italian Space Agency to upgrade Node 3 to serve as a habitat.

The Psychology of Living and Working in Space

Psychological studies of astronauts aboard the space station will help crews to perform better in space and help us work together better here on Earth.

credit: NASA

Studying the psychological effects of living and working together in the confined spaces of the ISS will enable researchers to make recommendations about better preparing astronauts for such missions and supporting them once they are aboard the station.

In recent years "teamwork" and "team-building" have been catchphrases of the workplace environment. For most people, however, worrying about getting along with their co-workers and working together for the common good may occupy only a small amount of their time. But what if you and your co-workers were confined to a small space, together for 24 hours a day in an inherently dangerous workplace, and unable to get away from each other because you were orbiting more than 350 kilometers above Earth?

That is the work situation faced by the crews who staff the International Space Station (ISS). Station crewmembers live and work together for up to four months at a time. While aboard the ISS, their primary contact outside the spacecraft is with ground control personnel, who support them in all tasks.

Principal Investigator Nick Kanas, a professor of psychiatry at the University of California, San Francisco, and associate chief of the Mental Health Service of the San Francisco Department of Veterans Affairs Medical Center, has been at the forefront of research into understanding the factors affecting the interpersonal relations among crewmembers as well as their interactions with ground control personnel. He hopes to use the information he gains from his studies to make recommendations to NASA management about issues relating to crew training and in-flight support.

Kanas' work aboard the space station is an extension of his previous studies of the astronauts and cosmonauts involved in the shuttle/*Mir* program. His current study will involve the crews of at least five different missions aboard the ISS. In addition, Kanas will also obtain data from ground control personnel supporting the missions both in the United States and in Russia, who will represent a comparison group for this study.

Says Kanas, "From the viewpoint of the average person, space is a unique experience where crewmembers are forced to work with each other in isolated and confined conditions. As a result, the crewmembers are exposed to interpersonal pressures that also may occur in Earth-bound work environments, although perhaps in an attenuated form.

"We expect to learn a lot about the behavior of people in terms of tension and cohesion and factors that are related to stress and how they affect tension, cohesion, and leadership in space." Some of this information will also be useful for people on the ground who want to be able to get along better with their co-workers and their bosses.

Questions, Questions

During the ISS study, subjects in space and on the ground will complete a questionnaire once a week. The questionnaire has two parts, a mood section and a group and work environment section, both of which are standardized psychological instruments. Additionally, there is a critical incident log in which study participants can describe any significant incident in their own words.

The mood questionnaire consists of 65 adjectives, like "sad," "angry," "nervous," and "lonely," and the subjects rate their mood for the past week in relationship to these on a scale from "not at all" to "extremely." Those ratings are then added up to get overall subscale scores, like tension, depression, and vigor. From these subscales, the researchers can develop a view of average crew emotional state.

The group and work environment scales are a series of questions that describe different kinds of group activities. The subjects review the descriptions and rate them as to how well they describe the subjects' work group each week. The researchers can then add up answers to all the questions and obtain group-related subscale scores, like cohesion, order and organization, and leader support.

The actual process of collecting the research data has been designed around protecting confidentiality for study participants. Each subject chooses a unique identification code that is known only to that participant, and this code is used to access and fill out the questionnaires. In space, the questionnaires are completed on a computer, and responses are immediately encrypted. The encrypted data are returned to Earth via diskette, where the researchers decode them and analyze the data.

What Has Gone Before

On Russian Space Station *Mir*, Kanas and his co-investigators made several findings about the group dynamics of working in space. Displacement, the phenomenon in which people under stress take out their feelings on someone else rather than the person or situation that may be the actual cause of that stress, was evident both on *Mir* and in mission control: during stressful times, *Mir* crewmembers perceived a lack of support from ground control personnel, and ground control personnel perceived a lack of support from their own managers.

Although the researchers predicted that there would be increased tension and decreased cohesion and perception of leader support during the second half of the missions, they found that their predictions held only for leader support.

Americans aboard *Mir* also exhibited what Kanas termed a "novelty effect." When the researchers looked at some of the subscales related to self-discovery, task orientation, order and organization, and cohesion, they found that scores on these scales were significantly raised for American astronauts only during the first few weeks of the mission. Says Kanas, "We think this is from being up in space on *Mir* for the first time on a new mission. It's a period of learning a lot about yourself and getting oriented and reacting to the excitement of a new experience." This novelty effect persisted for several weeks, after which the scores on these measures gradually returned to a baseline and then did not change much for the rest of the mission.

"From the viewpoint of the average person, space is a unique experience where crewmembers are forced to work with each other in isolated and confined conditions."
— Nick Kanas
principal investigator

Despite the novelty effect, "on several subscales, the Americans, both in space and on the ground, were significantly less happy with their work environment than the Russians," continues Kanas. "I think the explanation, for the people in space anyway, might have been related to cultural factors, but also to the fact that there was only one American and two Russians on all of the missions." Because there was always only one American, the astronaut held a true minority status, and this social isolation could have contributed to the dissatisfaction the Americans felt.

Looking Forward

With the new study, Kanas hopes that greater variability in the makeup of crews will enable him and his co-workers to test what psychological effects may be related to cultural differences and what effects may be the result of minority status. It is for this reason that the researchers have added a culture and language questionnaire to the current study.

All subjects, both space station crewmembers and ground control personnel, will complete a culture and language survey. This is a series of questions regarding the number of countries the subjects have lived in, and for how long; how many languages they speak fluently; their views about language and dialect; and whether they have friends from different national and cultural groups. The purpose of this survey is to gain a sense of the cultural issues that can affect working relations among crewmembers.

"It is a measure to tease out the cultural backgrounds of our subjects," says Kanas. "If we find that problems are always related to being the single representative from your country in the crew, then we might infer that dissatisfaction comes from a minority status. If, on the other hand, we find that only members from a single cultural group have problems, then we might be able to say that the problems are more cultural."

The *Mir* study provided additional revelations that Kanas hopes to pursue further with the ISS study. Astronauts and cosmonauts routinely scored high on scales measuring positive dimensions and low on scales measuring negative dimensions. Kanas explains, "Even though [the scores] changed when things got rough on board — they might have gotten less positive or more negative — the number values were not as great as they were in similar studies with other work groups on Earth using these measures." Kanas believes that these differences come from the fact that astronauts come from a highly selected population that is used to dealing with psychologically stressful situations. "I think it reflects the kind of people that are ultimately selected for space programs," he remarks. "We're getting a kind of blunting response to events based on the fact that these are highly trained and competent people who go through life dealing with its stresses in a way that is less reactive."

Clearly Kanas would like to have as many diverse crews as possible for his study to be able to get the best information possible, but he notes that it's basically a naturalistic study, since the researchers have no control over the makeup of the crews. Says Kanas, "The more women and the more non-Americans and non-Russians we get in our subject sample, the better." But, he acknowledges, "we'll study what we get."

The researchers will be collecting demographic information, so they will be

continued on page 25

Gene Therapy: Putting Muscle Into the Research

Bioartificial muscle implants could attenuate or perhaps prevent muscle loss among astronauts in orbit and patients with muscle-wasting diseases on Earth.

When astronauts spend time in space, they also spend some of the hard-earned muscle mass that they've built up on Earth prior to their flights. In the microgravity environment of a spacecraft in orbit, muscles atrophy quickly. The body perceives that it does not need muscles to be as strong, resulting in a decrease of muscle mass by as much as 5 percent a week — up to about 20 percent over time in the muscles that are used more to fight gravity on Earth, such as those in the calves and along the spine.

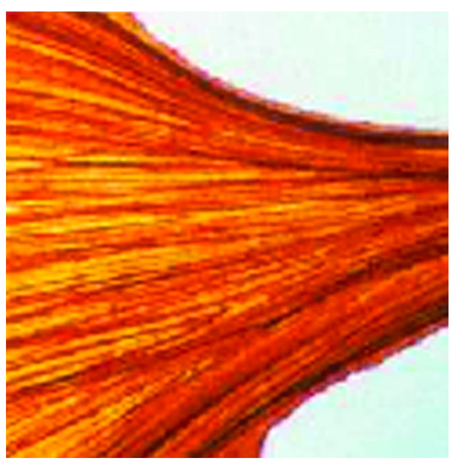
To help attenuate this muscle loss, and perhaps even prevent it, Principal Investigator Herman Vandenburgh, of Brown University, is studying the effects of a protein that could be manufactured in small bioartificial muscle implants. The results of his work, supported by NASA's Fundamental Space Biology Division, could mean better muscle condition in astronauts on long-term spaceflights. On Earth, results also could help the elderly suffering from frailty and patients battling muscle-wasting diseases such as AIDS.

Testing the Strength of an Idea

How well muscles are conditioned depends on how much the muscles are required to work. When the workload of muscles is reduced, such as when they are not bearing much weight in space or during long-term bed rest on Earth, the rate at which the muscles make new proteins decreases, resulting in muscle atrophy. Vandenburgh learned this cause-and-effect from engineered avian (bird) tissue experiments he conducted on STS-66 in 1994 and STS-72 in 1995. Based on this knowledge, he formed a hypothesis for attenuating muscle atrophy. "Having that piece of information," Vandenburgh remembers, "was really what keyed us into the possibility that [the protein] insulin-like growth factor 1 (IGF-1) might be effective, because the major effect of IGF-1 on muscle cells is to increase synthesis of [other] proteins [needed by the muscles]."

To find out just how effective IGF-1 is, Vandenburgh and colleagues Paul Kosnik, Courtney Powell, and Peter Lee have been developing a model for atrophy using bioartificial muscles in his laboratory. Vandenburgh explains, "It's an Earth-based model for what we think happens in space, so that we can grow the bioartificial muscles in our lab and then we can induce atrophy by reducing the tension on the muscle, which is what we think happens when [astronauts] go into space. The muscles generate less force, so they don't make as much protein and they waste away."

The bioartificial muscles Vandenburgh uses on the ground start as avian, mouse, rat, or human cells. He engineers the cells in a culture chamber, where they multiply and grow into small muscle-like samples that are large enough to manipulate with the hardware he has developed. "The hardware is a self-contained, computerized system that allows us to very precisely control the length of the bioartificial muscle down to the micron range," he describes. Controlling the length of the muscle controls the tension on it. Greater tension simulates a muscle that is in use; less tension, one that is at rest.



credit: NASA

Bioartificial muscles grown in Vandenburgh's laboratory are a crucial element in his research. He's testing to find the dosage of IGF-1 that will stimulate new protein production in muscles, thereby attenuating atrophy in astronauts and in patients with muscle-wasting diseases on Earth.

"We have a force transducer connected to one end of the bioartificial muscle," he continues. "This allows us to measure the actual force, or contraction, that the muscle can generate when we electrically stimulate it, so that we can actually measure the work performed by the muscle. If the muscle is atrophying, that would be reflected in a decreased ability to generate force and do work." With this hardware, Vandenburgh will be able to test IGF-1 and get a better idea of how much of the protein is needed to stimulate new protein production and attenuate atrophy in tissue grown from avian cells (a good model system for what happens in human and other mammalian cells) for the next flight of his experiment in 2004. He explains, "We're pretty confident that something like IGF-1 will work, but we don't know what dose will be most effective."

Developing a New Delivery System

To administer the doses he is testing, Vandenburgh uses gene therapy, which should be more effective than injections in delivering the protein. He explains the problem with injections, a common way of delivering already available growth-factor treatments for various conditions, such as dwarfism: "These growth factors turn over very quickly in the body. For instance, IGF-1 probably has a half-life of a couple hours in the body, so in order to get effective doses when you inject it, you have to inject high concentrations, and you have to inject it every day. The problem with injecting high concentrations is that it can lead to adverse side effects."

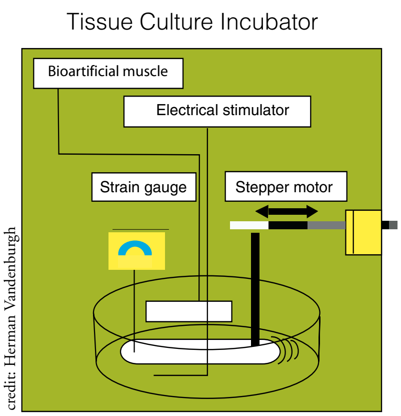
So instead, he puts the deoxyribonucleic acid (DNA) sequence for the IGF-1 into a replication-deficient retrovirus. Retroviruses carry ribonucleic acid (RNA) rather than DNA, but this type of virus cannot trigger replication of its own RNA in a host cell. Instead, it carries the genetic material of a foreign DNA for replication. Then Vandenburgh puts the engineered retrovirus into the cells of engineered muscle tissue to allow the foreign DNA to stably incorporate into those cells.

"Viruses are very efficient at getting into cells the material you want," he explains. The virus attaches to a host muscle cell and then recruits the host cell's enzymes to copy the genetic material of the IGF-1. As the IGF-1 is manufactured, it builds up in the cell and then is released to surrounding cells. Secretion of the factor is at a physiological level, similar to the level at which the body would supply the factor to muscle cells were they supporting a normal workload.

In the future, the bioartificial muscles could be used in a device implanted subcutaneously (under the skin) as a living "little protein factory," as Vandenburgh calls it, delivering proper dosages of the protein to the whole body for 6 months or more. This nature-simulating delivery system for IGF-1 could mean a drastic reduction in how many needles and side effects that patients with muscle atrophy would have to deal with.

Supporting Basic Research

When that day comes, huge numbers of people may benefit. Not only might astronauts keep their muscles in better condition, but elderly people, AIDS patients, and people with congestive heart failure may also redevelop stronger, healthier muscles. In addition, the technology could be used with other proteins to treat other protein-deficiency diseases (see sidebar), such as diabetes.



credit: Herman Vandenburgh

The hardware Vandenburgh's research group uses in his ground research controls the length of a bioartifical muscle (made from engineered tissue), and thereby the tension on it. The strain gauge measures how much "work" the muscle responds with when it is stimulated by the stepper motor.

The irony of all the potential this technology has on Earth is that originally, the IGF-1 research was geared for astronauts only. "We started out with our primary interest in space biology without any real concept that it might have direct Earth-based applications. So it was a very basic research project initially that was funded by NASA to understand what happens in space, and how we might be able to prevent the wasting that occurs [in astronauts]. Then it really evolved into a very important potential Earth-based therapy."

Vandenburgh notes the significance of conducting basic research such as his: "One of the points we try to make is that fundamental biology research is very important because you never know where it's going to lead. It's like the molecular biologists back in the '70s who were studying *E. coli* — really, all of that evolved into doing the human genome project, sequencing DNA in humans. No one would have envisioned back then that the research would have that kind of application. So even when you don't envision how [a microgravity experiment] could help people on Earth, these basic research problems can go in different directions and have an impact on treating diseases on Earth."

Julie Moberly

Implanting for the Future

In conjunction with preparations for the next flight of Vandenburgh's experiment, he is developing a commercial implant device that could be used on Earth to manufacture and release a variety of different proteins, such as insulin for diabetics, human growth hormone for children with dwarfism, or factor VIII for hemophiliacs. The device, which would be inserted under the skin, is similar in concept to a commercially-available device used for delivering contraceptives for periods of up to five years. It could deliver small physiological doses of the needed protein for six months or more, eliminating the need for daily injections of large pharmaceutical doses. "The difference," Vandenburgh explains, "is that the new implant is a living device, not just a repository forwarding manufactured compounds."

His company, Cell-Based Delivery Inc., conducted early tests on rats with their hind legs suspended to induce atrophy. (The test is a standard model that was developed by Principal Investigator Emily Morey-Holton, of Ames Research Center.) Seventy percent of normal muscle wasting was prevented in rats that received growth factor through implants. Atrophy could not be prevented in rats that received daily injections of the factor instead of the implant.

Cell-Based Delivery also has already shown feasibility for the device in tests of over a dozen sheep. In those tests, Vandenburgh and his team were able to deliver IGF-1 at a constant level for up to 30 days, the length of time they kept the experiments going. The company has just completed a series of large-animal studies and is ready to conduct a 6- to 12-month safety (phase I) study for the U.S. Food and Drug Administration. "Once that's been completed," Vandenburgh projects, "we hope to be able to start treating patients in the next 12 to 8 months in a small phase II clinical trial. If it's successful, it will be a revolutionary way of delivering proteins."

For more information, contact *Herman_vandenburgh@ brown.edu* or go to *http://science.nasa.gov/headlines/y2001/ ast02aug_1.htm?* list78048

What's in a Quantum Whistle?

The discovery of a quantum gyroscope could provide the most sensitive detection yet of the Earth's rate of rotation.

Imagine if you could use a whistle to detect changes in Earth's rotation rate or perhaps to test parts of Einstein's theory of relativity. NASA Principal Investigator Richard Packard and his colleagues at the University of California, Berkeley, have brought technology one step closer to just such a reality. The whistle in this case is not an ordinary whistle, such as a law enforcement officer or sports coach might wear, but rather a superfluid quantum whistle.

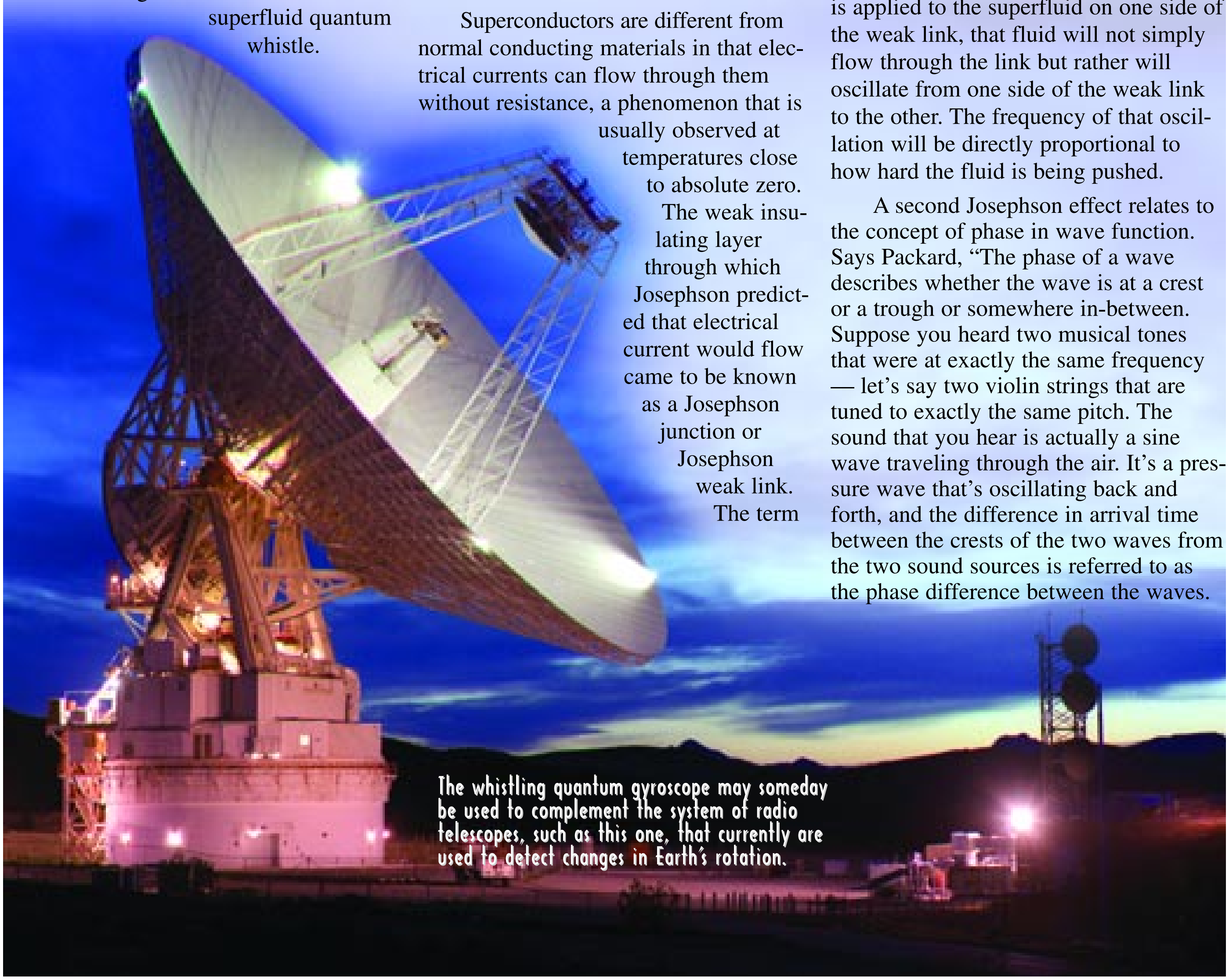
Josephson's Prediction

According to Packard, to understand just what a superfluid quantum whistle is, you must first look back to 1962, when Cambridge University physicist Brian Josephson made a prediction. Josephson hypothesized that an electrical current could travel between two superconducting materials even when they were separated by a thin insulating layer.

Superconductors are different from normal conducting materials in that electrical currents can flow through them without resistance, a phenomenon that is usually observed at temperatures close to absolute zero. The weak insulating layer through which Josephson predicted that electrical current would flow came to be known as a Josephson junction or Josephson weak link. The term "Josephson effect" has come to refer generically to the different behaviors that occur in any two weakly connected macroscopic quantum systems — systems composed of molecules that all possess identical wavelike properties.

Superconductors and superfluids are both examples of these quantum systems. The best-known example of a superfluid is liquid helium that is cooled to near absolute zero, at which point the helium flows without friction. Electrons passing through a superconductor can also be described as a superfluid because the electrons *flow* without resistance. In the case of superfluid systems, one predicted Josephson effect is that when two superfluids are weakly connected and pressure is applied to the superfluid on one side of the weak link, that fluid will not simply flow through the link but rather will oscillate from one side of the weak link to the other. The frequency of that oscillation will be directly proportional to how hard the fluid is being pushed.

A second Josephson effect relates to the concept of phase in wave function. Says Packard, "The phase of a wave describes whether the wave is at a crest or a trough or somewhere in-between. Suppose you heard two musical tones that were at exactly the same frequency — let's say two violin strings that are tuned to exactly the same pitch. The sound that you hear is actually a sine wave traveling through the air. It's a pressure wave that's oscillating back and forth, and the difference in arrival time between the crests of the two waves from the two sound sources is referred to as the phase difference between the waves.



The whistling quantum gyroscope may someday be used to complement the system of radio telescopes, such as this one, that currently are used to detect changes in Earth's rotation.

credit: NASA

"So these quantum mechanical waves that describe superfluids, they're waves in the mathematical sense that a sound wave is, and they have a phase." When the superfluid flows from one side of the weak link to the other, a phase difference occurs between the two portions of superfluid.

The Proof Is in the Whistle

These two Josephson effects — oscillation when a force is applied and a phase difference between the linked quantum systems — are expressed in mathematical equations that have been proven using superconducting materials. In the early 1960s, superconducting quantum interference devices (SQUIDs) were developed. A SQUID essentially consists of a circular loop of superconducting material that has at two places along the loop a "break" in which a thin insulating layer has been inserted so that the different sections of superconducting wire are weakly connected through this layer. If a current is applied from the top of the loop, the two weak links act as one weak link, and as the current is pushed through the system, instead of traveling steadily through the weak links, it oscillates back and forth, as predicted by Josephson.

Says Packard, "The frequency of that oscillation will be proportional to how hard you push, meaning how high the voltage is, but the magnitude of that oscillation turns out, for superconductors, to depend on the strength of the magnetic field that's going through the circular circuit. And that fact forms the basis for the most sensitive detectors of magnetic field."

What Packard and his colleagues did was to make an analogous device using superfluid helium-3 instead of a superconducting metal. The device they developed is similar to that described for the SQUID, except that in the place of wires for conducting electric current, a donut-shaped hollow tube is used to conduct the superfluid helium (see Figure 1). The weak links, rather than being breaks in the wire as in the SQUID, are actually partitions that contain extremely small holes to connect the superfluid systems on either side of the partitions. "This is geometrically the same as the superconducting circuit, except that we have a neutral fluid flowing through it instead of a charged fluid," notes Packard.

The Berkeley group's initial experimental aim was to verify the prediction that pressure applied to this system would result in the superfluid's oscillating back and forth through the weak link, and that the frequency of the oscillation would be proportional to the amount of pressure applied across the system. It turned out that Packard and his colleague Séamus Davis discovered this frequency of oscillation by listening. Says Packard, "When [the oscillation] was first detected in a single weak link, it was actually detected with a set of headphones. We were looking for an electronic signal that represented this oscillation and didn't see it, but when we connected the electronic signal to headphones and listened, we could hear a distinct whistling sound, so that's what's meant by the quantum whistle." The Berkeley team also found the whistle in the double weak link device, thus demonstrating that the two weak links did indeed act as one weak link, as in a SQUID.

Another prediction for the superfluid device arose from experience with the SQUID. When superconductors were used as the linked quantum systems, the magnitude of the electric current oscillation depended on the magnetic field passing through the loop. For weakly linked superfluids, the magnitude of oscillation should depend on the rotation rate of the loop. As the system is rotated, the magnitude of the fluid oscillation — the whistle — should show a similar classic interference pattern (see Figure 2).

If the loop is not rotating at all, then the whistle will have a particular magnitude. As the loop begins to rotate slowly, the magnitude of the whistle should begin to decrease and continue to decrease to zero amplitude as the loop rotates faster. Upon reaching zero amplitude, and as the loop continues to rotate even faster, the magnitude of the whistle will begin to rise and will continue to rise to a maximum, and then will start to decrease again. The research team expected to see this series of peaks, the interference pattern, because the superfluid exhibits a wave function (as predicted according to the Josephson equations). The magnitude of Packard's quantum whistle indeed varied with rotation according to the classic quantum interference pattern.

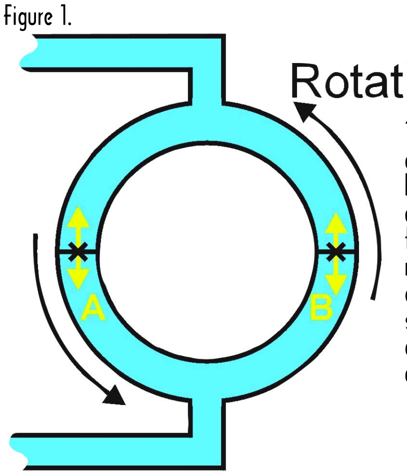
A Whistling Gyroscope

Just as a SQUID is an extremely sensitive detector of magnetic fields, the superfluid device is a sensitive detector of rotation. The Berkeley research team wanted to take this latter result a step further and show that their device could be used to measure changes in the rotation of Earth. Rather than rotating the device in the laboratory, the team used the fact that Earth itself rotates. Changes in Earth's rotation rate are extremely small and occur over a period of several days. On the time scale of the experiment, the researchers could not speed up or slow down the rotation of Earth, but they could reorient their device with respect to Earth's north-south axis.

Says Packard, "If our device had been bigger and had the sensitivity to detect those tiny changes in Earth's rotation, then we would have left the loop alone and waited for Earth to speed up or slow

continued on page 25

Figure 1.



The loop of Packard's quantum device allows two superfluids to be weakly linked, creating a quantum whistle. The Xs indicate the weak links, in this case thin membranes of silicon nitride each perforated with 4,225 small apertures. Each aperture is about 500 times smaller in diameter than a human hair.

ISS Plant Experiment Feeds Young Minds and Industry

Arabidopsis plants grown in Advanced Astroculture™ growth chambers are engaging students in science experiments and providing plant cell information for industry.

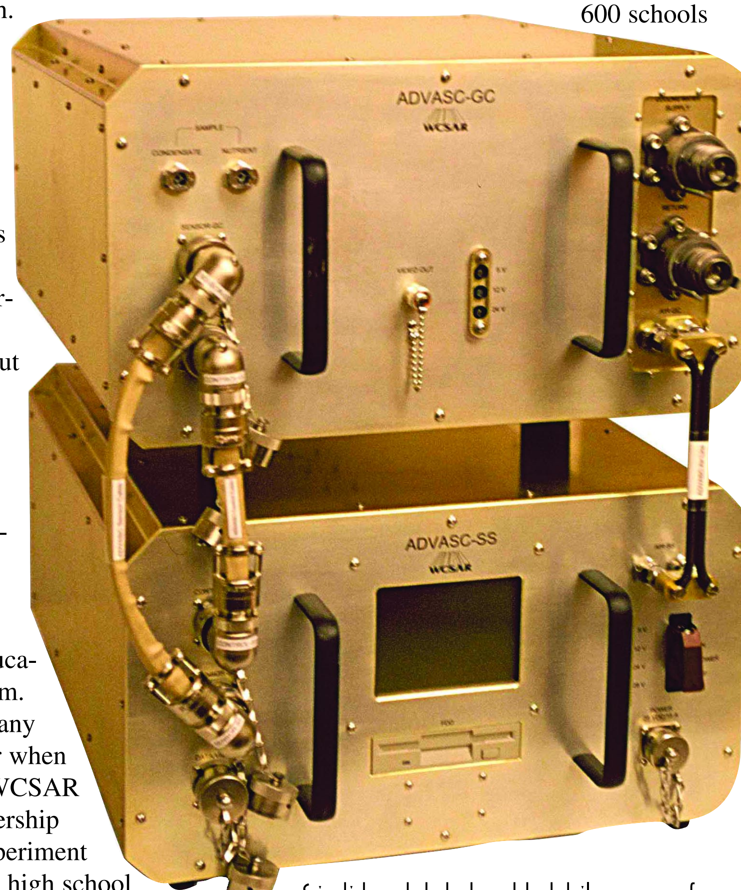
Many people have their first gardening experience growing radishes. The plant's small size and fast growth rate make it an excellent choice for the novice who wants encouraging results in a hurry, often from a flowerpot-sized plot. These qualities also are why *Arabidopsis* plants, from the Brassica family, which includes species such as cabbage and radish, were selected for the first plant growth experiment to be conducted on the International Space Station (ISS). The experiment was deployed on STS-100 in April 2001. Weijia Zhou, director of the Wisconsin Center for Space Automation and Robotics (WCSAR) commercial space center and principal investigator for this experiment, explains that the size and fast life cycle of *A. thaliana*, a small, leafy cress, were great advantages for a space mission: "In about six to seven weeks, you can do seed-to-seed growth. And overall, it's not a bushy plant, so it's easy to cultivate in a restricted space."

Zhou and his team designed the Advanced Astroculture™ closed environment system for growing plants onboard spacecraft, where room is always at a premium and environmental control is very important. Zhou began developing the system several years ago as a means not only for industry to partner with WCSAR but also for NASA to conduct plant growth research in orbit. Advanced Astroculture, which just completed its first flight this spring, builds upon the validated Astroculture™ technologies that have already been flown on seven shuttle missions. The system provides an enclosed, environmentally controlled plant growth chamber that can support plant research for long durations in a reduced-gravity environment. Controlled environment parameters include the chamber temperature, relative humidity, lighting, plant fluid nutrient and water delivery, and carbon dioxide and ethylene concentrations in the chamber. State-of-the-art software precisely controls the environmental conditions within the chamber to provide an environment suitable for a wide variety of plant species to grow. Auto-prime technology eliminates the need for power during shuttle ascent.

All these controls are necessary to learn in what ways plant growth in microgravity is different from plant growth on Earth. The Advanced Astroculture experiment using *Arabidopsis* plants will provide researchers and other groups the information they are looking for about space-grown flora.

Space Explorers, WCSAR's commercial partner for this experiment, develops commercial educational curriculum. What the company was looking for when it approached WCSAR to form a partnership was a space experiment that middle and high school students could participate in that would also contribute useful scientific knowledge. The answer was a plant growth experiment. *Arabidopsis* was selected as the sample plant for the advantages already mentioned, but also because it is often used as a model in plant research. In fact, it is the only plant for which there exists a complete set of genetic blueprints.

Students were involved early on in experiment planning by creating kits for *Arabidopsis* growth in the classroom. "The kit used a paper ream box to create a basic growth chamber," says Tad Theno, chief program scientist at Space Explorers. "Of course, it didn't have controlled humidity or atmosphere, but the consistency of the soil, the depth of soil, the nutrients given the plants, the nutrient concentration, how often the plants were fed, the number of hours of light received, and the light's intensity could all be controlled" and recorded. About 600 schools



credit: WCSAR

Scientists and students watched daily progress of *Arabidopsis* plants this spring on the ISS through a video camera inside the Advanced Astroculture chamber.

participated in growing *Arabidopsis* plants using the kits, each of which contained instructions for growing the plants under differing conditions.

“The ISS is very much state-of-the-art-technology, and it should be equipped with state-of-the-art science research capabilities. Our plant growth chamber is one of them.”

–Weijia Zhou, principal investigator

“Within a single class, you might have a student growing the plants in dirt with a 150-percent concentration of fertilizer and beside him a student growing them in a 25-percent fertilizer. So there was a variety within the classroom, and they could also compare classroom results to those of all the other students across the country,” explains Theno. Students counted leaves; measured plant height; counted the number of flowers, fruit, and seed pods; and recorded when each major event in the plant cycle occurred, as well as any unusual events, to create a developmental timeline. The students kept careful records of the results and entered them in an online database.

Space Explorers and WCSAR used the data to determine the final parameter set points for conditions for the spaceflight experiment. Thus, the students did preliminary ground-based research for the experiment. They also had access to the research data from the spaceflight experiment while it was conducted onboard the ISS, again through the online database, so they could compare their classroom results to what happened to the plants in space.

Advanced Astroculture represents a major milestone in the development of sustained long-term plant growth in orbit. With the completion of this first experiment using WCSAR’s system on the ISS, the success of the technology has been demonstrated. “The ISS is very much state-of-the-art-technology, and it should be equipped with state-of-the-art science research capabilities,” says Zhou. “Our plant growth chamber is one of them.”

Many companies are also interested in the results of the experiment because they want to know what happens within the plants themselves while they are in space. “We know from our previous commercially sponsored experiments that microgravity will affect biosynthesis,” explains Zhou. “That’s not just our finding. NASA has conducted more than two decades of research that agrees.” Biosynthesis is a focus of industry interest because it is the process by which plants produce secondary compounds, or metabolites. Companies want to know if microgravity alters the production of these metabolites, and then want to use that information to try to produce those products on the ground.

Industry needs two things from a plant experiment in space: seeds and plant tissue that contain the DNA and RNA information required to give clues as to how to control the production of metabolites and seeds. Once a plant dies, the tissue loses much of the RNA information and some of the DNA, Zhou explains, so “we want to sample the living tissues, to fix them in space, and to bring them back to the ground for analysis. We will compare the samples to those from plants grown on Earth to see whether microgravity affected the gene expression and at what level. Because *Arabidopsis* has been completely mapped out genetically, we can do a complete analysis.”

For the plant experiment on the ISS, there was not yet the capability onboard the station to freeze plant tissue. For the follow-up Advanced Astroculture experiment, which will go to orbit toward the end of 2001 on STS-108, there will be a refrigerator onboard that can preserve tissue samples for a limited time. The first *Arabidopsis* experiment did, however, produce seeds, which were harvested after the growth chamber returned to Earth in July. Growing a plant through its complete life cycle will attract future commercial partners for plant experiments on the ISS, according to Zhou.

credit: NASA

The plant growth experiment was the result of a commercial partnership between WCSAR and Space Explorers, a company that develops science curriculum. Students conducted the growth experiment on the ground using a classroom kit while astronauts on the space station tended the same type of plants, shown here at the end of the spring 2001 mission.

With the promising results the first commercial plant experiment has brought to the WCSAR, Space Explorers, agricultural industries, and NASA, it’s likely the ISS holds much more in store for every user who wants to see research capabilities grow.

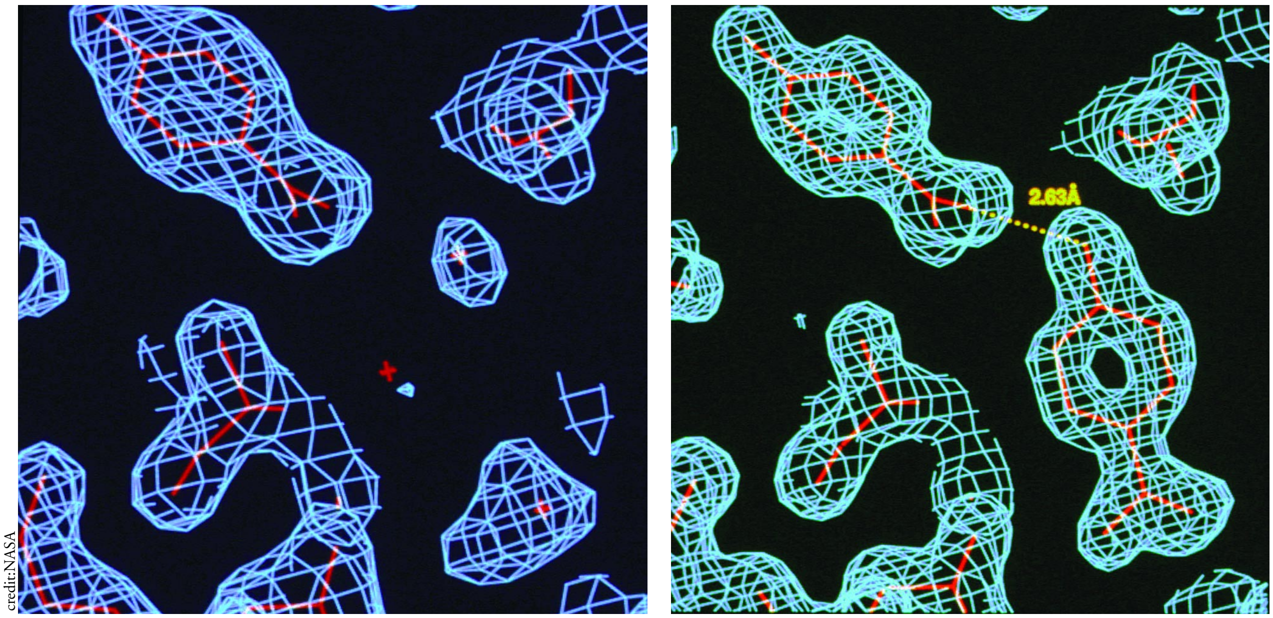
Julie Moberly and Katherine Rawson

For more information about Advanced Astroculture, visit the WCSAR web site at *http://wcsar.engr.wisc.edu/* or contact Weijia Zhou; phone: (608) 262-5526; e-mail: *wzhou@facstaff.wisc.edu*. For more about the Space Explorers curriculum, visit *http://www.orbitallaboratory.com* or contact Tad Theno; phone: (920) 339-4600; e-mail: *tad@space-explorers.com*.

Picture This . . .

Images must help the reader bridge the gap between the familiar, everyday world and the esoteric, often microscopic, world where an experiment is conducted.

As the newest enterprise, the Office of Biological and Physical Research (OBPR) truly represents the "lifeblood" of NASA. The dynamic processes of biological and physical sciences research in microgravity further our understanding about human presence and nature's forces in space. OBPR's research initiatives support the establishment of a permanent presence in space, from engineering designs and advances in life support systems that enable long-duration missions to ongoing physical sciences, life sciences, and commercial research onboard the orbiting laboratory of the International Space Station. Technologies will be developed to extend or mimic biological processes within living systems. Techniques and processes will also be developed to unlock the mysteries of fundamental biological and physical processes involved in the evolution, development, and adaptation of life to Earth and microgravity environments. Last, but by no means least, scientists will use the microgravity environment of orbit to benefit life on Earth.



Few people will fully understand a wire-frame diagram of electron density in an insulin molecule, but they will appreciate that microgravity research added detail (right) that was unavailable in ground-based studies (left).

credit:NASA

The OBPR education outreach and public outreach community is dedicated to building an innovative program that will excite and engage audiences in OBPR research by bringing to academic, professional, and general public audiences a fundamental understanding of what OBPR research is taking place, why it is taking place, and why it has meaning to their lives. OBPR also will seek to be a catalyst for increased scientific literacy. Future issues of *Space Research* will discuss important topics about educational outreach and public outreach.

A key element of all outreach is the use of effective visual means of presentation. In an information age driven by a growing deluge of images, pictures — even simple graphs — may be the best way to draw an audience into a story. Subjects that are rich in visual images attract readers. But care must be taken in preparing an image to ensure that it is scientifically accurate, lest an inaccurate image take hold of the imagination of the lay public.

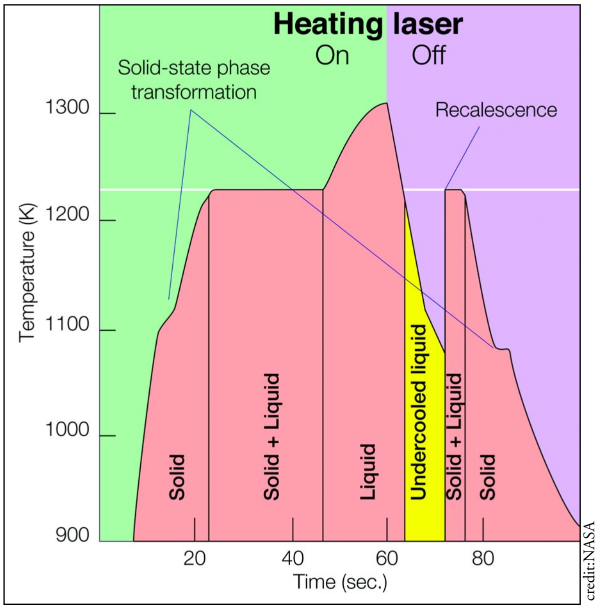
An image's meaning "is in the eye of the beholder and not necessarily in the mind of the scientist," cautions Boyce Rensberger, director of the Massachusetts Institute of Technology (MIT) Knight Science Journalism Fellowships and co-chair of MIT's Image and Meaning Conference, held June 13–16, 2001. For instance, the original Neils Bohr model of the atom — electrons orbiting a nucleus like a tiny solar system — is "so simple, so attractive, so wrong," says Thomas Greytak, associate department head for education at MIT and a co-investigator on research into Bose-Einstein condensation (BEC), a quantum physics phenomenon. Greytak says that a good scientific icon should be visually attractive, accurate, and convey at least one new concept to the viewer. As another example of an image that doesn't quite work, Greytak showed an artist's concept of BEC. While it correctly showed atoms condensed into a small volume at a low energy state, it also gave a mistaken impression of order in such structures by showing atoms lined up like soldiers at attention.

Other types of miscommunication can also occur when rendering images. This is especially true when three-dimensional graphics can give credibility to fuzzy data, cautions John Abele, of Boston Scientific, a maker of diagnostic instruments. “When does clarification become manipulation?” he asks. One participant at the MIT conference observed that the human mind exercises a “mental snap-to grid” effect on images: “Everything you see snaps to what you know.” An example of this is that Japanese artists, seeing their first American sailors in 1849, depicted the foreigners with Asian-looking eyes. Thus, it is imperative that researchers clarify their images so that they cannot be misconstrued.

“You have to meet the public on their own terms and speak in a language they can understand,” says John Rennie, editor of *Scientific American*. “You have to get across what is wonderful as well as what is true.” Some artistic license may be required to bring up details, he noted. The visual as well as the written story has to be educational, inspiring, graspable, and interesting. And when you succeed, Rennie said, “You will finally have something that helps your mother know what you do for a living.”

Bearing in mind the importance of visual and textual accuracy, researchers are encouraged to support the NASA Image Exchange (*http://nix.nasa.gov*) to help reporters and teachers tell our story. Images and captions can be uploaded by anonymous FTP to *ftp://ftp.msfc.nasa.gov/microgravity/new_pix.*

Dave Dooling



In this graph of a heating profile for the Electrostatic Levitator, all phases have the same color except the deep-undercooled region, the area of interest.This color choice draws the reader to the key information in the graph.

Image Guidelines

Images must help the reader bridge the gap between the familiar, everyday world and the esoteric, often microscopic, world where the experiment is conducted. And they must meet the publisher’s mechanical requirements. Here are some hints:

- Take high-resolution images. Most publications print at up to 300 pixels per inch. A striking 2-inch screen image is less than 1/2-inch wide in print. Make pictures at least 1,500 pixels in the longer dimension to allow for at least a 5-inch-wide image in the final print.
- Send images as TIFF or uncompressed JPG files (Microsoft PowerPoint and Microsoft Word are totally unsuited for transferring images). Send vector-based artwork in IDL postscript or Acrobat PDF formats.
- Include the familiar. A sample cell next to a 10-centimeter ruler tells nothing; between fingertips, it shows both size and fragility.
- Show the heart of the experiment. The tiny electrodes that will vibrate inside supercritical xenon tell far more than the Get Away Special canisters that hold the apparatus.
- Illustrate with analogs. The sample in the Supercritical Viscosity of Xenon experiment and pumpkin pie filling both exhibit the shear-thinning effect.
- Use before-and-after or 1 g versus microgravity images to show the value added by going to orbit.
- Offer multiple views to give editors more choice and flexibility.
- Allow some sacrifice of precision (but not accuracy) to get the point across.
- Include captions.

Overview of OBPR's Programs

NASA's fifth and newest enterprise, the Office of Biological and Physical Research, encompasses a wide variety of research efforts and a new publication to cover them.

An OBPR Primer

NASA's fifth and newest enterprise, the Office of Biological and Physical Research (OBPR), brings to the era of the International Space Station a rich diversity of research efforts. As described in this issue of *Space Research* and showcased in future issues, research within this enterprise includes studies that will enable a crew to safely live and work in space for extended durations and efforts that support fundamental science investigations. Such research uses ground-based laboratories and the unique microgravity environment of low–Earth orbit to further the frontiers of knowledge in biology, chemistry, combustion, nanotechnology, physics, and other life and physical sciences. In addition, research sponsored by OBPR promotes the use of space for commercial research leading to new or improved product development.

To place the research highlighted in this issue and featured in upcoming issues in proper perspective, the editors of Space Research are including a brief overview of the organizations and research goals of the Office of Biological and Physical Research. The following description of the divisions of Bioastronautics Research, Fundamental Space Biology, Physical Sciences, and Research Integration also provides a look at what is yet to come.

Bioastronautics Research Division: Bioastronautics includes biomedical research and human support technology development. Experiments focus on answering the challenges of safely living and working in space and on providing new information about how humans adapt to spaceflight. There are seven goals of the bioastronautics program:

- To understand the medical and human support requirements for protecting human health and well-being during spaceflight
- To identify and characterize the medical risks of spaceflight to humans
- To determine how the microgravity environment changes the behavior and function of biomedical systems (including heart and blood vessels, bone, muscle, nerves, and behavior) and human support systems (such as biologically based air and water reclamation and food production)
- To provide the scientific rationale and evidence that will aid in minimizing the negative effects of spaceflight
- To provide data and results that can be used to optimize crew health and performance
- To gain a better understanding of how crews interface with machines and with each other
- To develop the advanced life support and environmental monitoring technologies that will enable humans to live and work in space safely and effectively

An important corollary of bioastronautics research is that Earth-based benefits will result from NASA's investments in basic research and technology development. For example, many biomedical insights are required to address NASA's ability to maintain astronaut health and well-being during and after flight. Lessons learned during space research and technology development can be applied to specific populations on Earth, such as older individuals, patients confined to bed rest for extended periods, or remotely located populations requiring medical treatment. Human support technologies developed by NASA also have direct applications to agricultural production, remote sensing, and the detection and destruction of air and water, and the contamination of food.

Fundamental Space Biology Division: The goal of the Fundamental Space Biology Division is to effectively use microgravity and other characteristics of the space environment to enhance the understanding of fundamental biological processes. These insights will be used to develop an important biological database of information needed for long-duration human presence in space, to provide fundamental knowledge about the role of gravity in how living systems develop and function, and to support NASA's other biologically related programs and activities.

Specific fields of research include genetic traits and cellular function under microgravity conditions, developmental and integrative biology, and space biology of complex systems including evolutionary biology and research in the ecology of the space environment. These disciplines provide a continuum of research that allows for the study of biological processes at all levels of biological complexity. Researchers examine a wide range of specimens, from plant and animal cell cultures to whole organisms like insects, aquatic species, rodents, and plants. Their research provides unique information about how terrestrial life responds and adapts to the novel environment of space. In turn, this information is applied to better understand biological processes on Earth and to further NASA's goals of utilizing and exploring space.

Physical Sciences Division: The Physical Sciences Division fosters multidisciplinary research in fundamental and applied sciences, addressing the details of physical and chemical processes in both inert and biological systems. Disciplines include fluid physics and engineering, combustion science, biomolecular physics and chemistry, nanoscience, macromolecular and cellular biotechnology, fundamental physics, and materials science. Guiding the research in all of these fields are the three major goals of the program:

- To build and sustain a fundamental research program enabled by the space environment
- To create a knowledge base to enable future exploration mission technologies
- To return tangible value from the nation's investment in space

Physical sciences research encompasses a wide variety of areas. Microscale measurements taken in microgravity target the complex behavior of atoms. Such data may lead to scientific advances in atomic and condensed matter physics not realizable on Earth. Studies in three-dimensional tissue engineering and macromolecular crystallization may significantly advance fundamental knowledge in biotechnology, a field of study that could benefit significantly from long-duration microgravity research.

Experiments in fundamental fluid physics and combustion research have the advantage in a microgravity environment of greatly diminished gravity-driven sedimentation and heat transference. On Earth, heat transference causes circulatory movements in fluids; in microgravity, that movement is drastically reduced, so scientists can precisely and accurately measure physical and thermal properties of materials at high temperatures and in delicate equilibrium states. This precise measurement also enables experimental validation of fundamental theories of solidification.

Complementing the flight-based research is a strong ground-based program carrying out leading-edge research in all the above-mentioned disciplines. The Physical Sciences Division supports experimental, theoretical, and numerical modeling activities to develop the foundation for a rigorous and productive flight-based program.

Research Integration Division: The goal of the Space Product Development program is to use the microgravity environment of low–Earth orbit to foster commercial research that will lead to improved products and processes on Earth. Although there are several independent commercial initiatives supported by this division (and more independent initiatives are expected with the emergence of the International Space Station), the primary emphasis of the program to date has been on research efforts of the NASA-sponsored commercial space centers and their affiliates. In fiscal year 2000, there were about 140 industry affiliates of the commercial space centers. Each center is an individual consortium of academia, government, and the private sector. These centers support research in three major fields: biotechnology, agribusiness, and materials processing. In fiscal year 2000, there were about 75 individual product lines including the following:

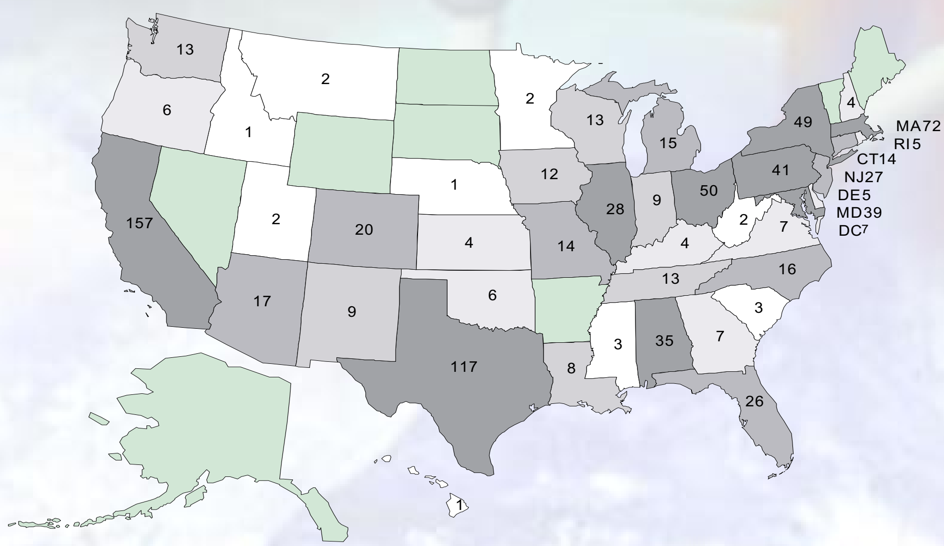
- Gene transfer research for improved crop development
- Improved insulin for diabetic patients
- Increased antibiotic production rates, which increase the yield and reduce the cost of the drug manufacturing process
- New sensor technology for medical diagnostic and electronics products
- Improved industrial refining processes
- Combustion research for improved fuel efficiency and for new fire-suppression technologies that are less harmful to the environment
- Advances in porous ceramic bone replacement materials that are longer-lasting and less likely to be rejected by the body

Some of the latest research advances in these exciting areas of science and commercial endeavors will be showcased in every issue of *Space Research.*

John Emond

Office of Biological and Physical Sciences (OBPR)

FY00 Total Investigations by State



* 886 Investigations funded in
42 States and the District of Columbia

* includes some investigations that may not have received FY00 funds

Meetings, Etc.

RESEARCH OPPORTUNITIES

http://research.hq.nasa.gov/code_u/code_u.cfm

Specialized Center of Research and Training

A NASA Research Announcement (NRA) soliciting proposals for a NASA Specialized Center of Research and Training (NSCORT) for Advanced Life Support in the Advanced Human Support Technology Program was released in July 2001. The center will support ground-based research to develop closed-loop life support. Aspects of this life support system include recycling air and water, producing crops and processing them into storable items or meals, and processing and recovering resources such as solid water. Proposals in response to the NRA were due October 16, 2001, and a selection will be made in February 2002.

NASA Bioscience and Engineering Institute

A Cooperative Agreement Notice solicited proposals from academic institutions or academic consortia to establish a NASA Bioscience and Engineering Institute. The institute will enable world-class research, development, technology transfer, and education in bioscience and engineering related to NASA's overall missions. Bioscience and engineering integrates physical, chemical, mathematical, and microgravity-based science and engineering fundamentals with biological concepts and methods for the study and understanding of medicine and health, and for the development of biology-inspired engineering systems. Proposals were due October 10, 2001; selections will be made in June 2002.

Materials Science: Ground-Based Research Opportunities in Biomaterials and Radiation Shielding

An NRA solicited proposals for ground-based research projects that will establish the core of a biomaterials program and for ground-based theoretical and research studies with an emphasis on radiation shielding. The biomaterials program will comprise research that is gravity-dependent, research that supports NASA's unique responsibilities of maintaining crew health and safety, and research that supports NASA's exploration goals. The emphasis for the radiation shielding program is on studies that would complete the measurement of required nuclear cross sections, complete the development of radiation transport codes, experimentally test and verify the radiation transport codes, and develop new radiation shielding materials. Proposals were due November 27, 2001, and selections for funding are expected to take place in May 2002.

Physical Sciences

The Physical Sciences Division plans to implement a single annual NRA that will include all of the physical science disciplines in thematic areas of research. Release of this NRA will occur early in fiscal year 2002. Staggered due dates will be used for proposals in the various disciplines and for special-focus theme proposals.

Editor's note: Research recently selected for OBPR funding is posted at *http://spaceresearch.nasa.gov/research_projects/selections.html.*

TECHNICAL MEETINGS

16th Microgravity Science and Space Processing Symposium and 40th AIAA Aerospace Sciences Meeting and Exhibit

Reno, Nevada
January 14–17, 2002
http://www.aiaa.org

The symposium focuses on issues related to materials processing in the microgravity environment, the sensitivity of experiments to various disturbances, and partial-gravity science in support of future space exploration and in-situ resource utilization. Topics will include biotechnology, combustion science, fluid physics, fundamental physics, materials science, and acceleration measurement.

Space Technology and Applications International Forum (STAIF) 2002

Albuquerque, New Mexico
February 3–7, 2002
http://www-chne.unm.edu/isnps/staif

STAIF is a major international technical forum hosting six concurrent conferences. This forum promotes international participation and provides for a timely exchange of information among technologists, academicians, industrialists, and program managers on technical and programmatic issues related to inexpensive access to space and space commercialization, exploration, and the potential for performing scientific research and developing new technologies. This year's forum is titled "Education — The Pathway to Space." Among the six conferences offered in 2002 are the Conference on Thermophysics in Microgravity and the Reliability, Materials, and Radiation Effects Track Conference.

American Association for the Advancement of Science (AAAS) Annual Meeting

Boston, Massachusetts
February 14–19, 2002
http://www.aaasmeeting.org

The theme of the 2002 annual meeting of the AAAS is "Science in a Connected World." The meeting will consist of plenary lectures, topical lectures, and symposia. Two symposia featured are "Genomes Around Us: What Are We Learning," and "Nanotechnology: From Computer Electronics to Medicine." NASA Principal Investigator Wolfgang Ketterle, of the Massachusetts Institute of Technology, will give a topical lecture titled "Bose-Einstein Condensates: Matter Made of Matter Waves."

Space 2002 and Robotics 2002

Albuquerque, New Mexico
March 17–21, 2002
http://www.spaceandrobotics.org

Space 2002: The Eighth International Conference and Exposition on Engineering, Construction, and Operations in Space, and Robotics 2002: The Fifth International Conference and Exposition on Robotics for Challenging Environments engages engineers, scientists, managers, and entrepreneurs from many nations in developing the space frontier. Presentation topics will include lunar and Martian bases, resources, mining, and construction; in-situ resource utilization; structures, materials, mechanics, and controls; and the International Space Station.

Experimental Biology 2002

New Orleans, Louisiana,
April 20–24, 2002
http://www.faseb.org/meetings/eb2002

This meeting serves as a forum for microgravity researchers in biomedical and life sciences who seek through their research to improve human health and productivity to communicate their results to the science community. The theme of this year's meeting is "Translating the Genome."

28th Annual Meeting of the Society for Biomaterials

Tampa, Florida
May 22–24, 2001
http://www.biomaterials.org/meetings/2002/index.htm

This meeting is held to disseminate information on research (including microgravity research) in biomaterials, including synthetic, natural, and biological materials, and on their uses in medical and surgical devices.

29th International Symposium on Combustion

Sapporo, Japan
July 21–26, 2002
http://combustioninstitute.org/1stannouncement.html

This biennial event draws scientists and engineers involved in combustion research from around the world. The technical program will consist of oral sessions of contributed papers organized into colloquia and poster sessions of work in progress. Colloquium topics will include Microgravity Combustion, Fire Research, Combustion Synthesis and Catalytic Combustion, Turbulent Combustion, Droplet and Flame Combustion, and New Concepts in Combustion Technology.

EDUCATION

Space Day 2002

on the Internet
May 2, 2002
http://www.spaceday.com

In the 2001–2002 school year, Space Day 2002, the annual global educational initiative, will focus young students' attention on space travel to Mars. Beginning in September 2001, educators are encouraged to access an array of innovative lesson plans and activities designed to excite and inspire students while underscoring the importance of math, science, and technology. Teachers and students may also participate in three Space Day online design challenges that emphasize cooperative learning. Full details and online registration are available on the Space Day web site.

PROGRAM RESOURCES

General Site

Office of Biological and Physical Research (OBPR)

http://spaceresearch.nasa.gov

- Latest Biological and Physical Research News
- Research on the International Space Station
- Articles on Research Activities
- Space Commercialization
- Educational Resources

Descriptions of Funded Research Projects

Science Program Projects

http://research.hq.nasa.gov/taskbook.cfm

Commercial Projects (also includes a description of the Commercial Space Center program and other information)

http://cscsourcebook.nasa.gov

down, but the device doesn't have the sensitivity yet to see those things, and what we were doing was a proof-of-principle experiment, so we could change the orientation with respect to the axis [to see if we would obtain the interference pattern]." The result of this reorientation of the loop was that the magnitude of the quantum whistle did indeed trace out the quantum interference pattern shown in Figure 2. The implication of this result is that if the loop is held stationary on Earth and Earth's rotation rate changes, then the magnitude of the quantum whistle will vary. For this reason, Packard's device is also known as a superfluid gyroscope.

Work for a Whistle

What sort of future does Packard see for his device? After additional research to demonstrate that the superfluid gyroscope is an extremely sensitive detector of changes in rotation, it could perhaps be used to complement the system of radio telescopes that currently are used to detect changes in Earth's rotation. This information is used to help scientists understand the physical properties and phenomena of Earth and is also fed into the Global Positioning System (GPS), which is used for pinpointing exact locations on Earth's surface. The precision required by the GPS necessitates sensitive detectors of rotational changes, and Packard hopes that one day his device will be able to provide just such information.

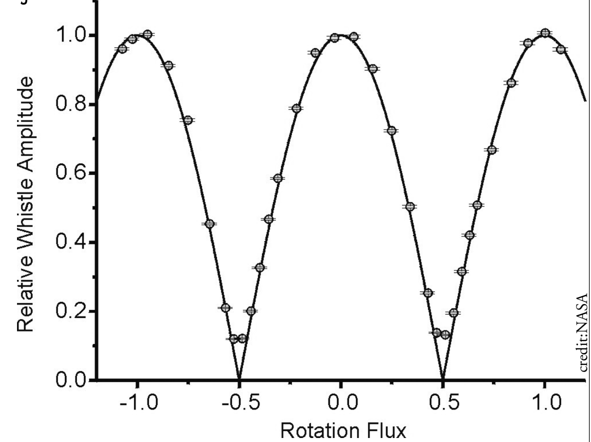
Packard also notes NASA's Gravity Probe B (GPB) project as another potential application for the superfluid whistle. The GPB project is placing the world's most delicate and sensitive mechanical gyroscope into space to attempt to detect a general relativistic effect predicted by Einstein. Packard hopes the quantum gyroscope potentially will provide sensitive measurements that might complement those obtained by a mechanical gyroscope. Mechanical gyroscopes are susceptible to torques due to Earth's gravity, but the superfluid gyroscope is unaffected by gravity. Also, because the area of a circle increases as the square of the radius as the circle is made bigger, making the loop of the superfluid gyroscope bigger will allow it, in principle, to detect smaller and smaller rotations, possibly enabling it to be a more sensitive detector of rotation than a mechanical gyroscope.

"But," says Packard, "it's still science fiction at this point." For now, the researchers are planning to isolate their system further in the laboratory to reduce its sensitivity to environmental noise and building vibrations. Then, if that step is successful, they will take the gyroscope to an environment that is away from human habitation and seismically quiet. This step will enable them to determine if there are any other technical limitations to the device's sensitivity. Only after those steps are completed would the researchers then consider sending the device into space. But until then, Packard and his team can truly be said to "whistle while they work."

Julie K. Poudrier

Packard's research team included J.C. (Séamus) Davis, a professor at the University of California, Berkeley; postdoctoral student Alexei Marchenkov; and graduate students Ray Simmons and Emil Hoskinson. For additional information on this research, see Simmonds, R. et al., "Quantum interference of superfluid ^{3}He," *Nature*, 412 (July 5, 2001): 55–58. For additional information on Packard's research, visit *http://physics.berkeley.edu/research/Packard/current_research/current.html.*

Figure 2.



The peaks and valleys on this graph show how whistle amplitude changes with changes in orientation with respect to Earth's rotation axis.

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able to break down the data in terms of male and female responses, nationality, and age groupings. However, if they don't get enough diversity in crew makeup, the ability to break out the demographics will be hampered.

Lessons Learned

The main thing Kanas hopes to get out of his research is information that can be used to provide training for future crewmembers and mission support staff that will allow them to be aware of the psychosocial issues that could affect them during their missions and help them to effectively cope with those issues. Kanas is working on obtaining funding for the next step of his work, a training module for crewmembers that is based on the insights gained from the *Mir* study and the ISS study. Ultimately, additional studies leading from Kanas' current study might be able to provide information that will aid in the selection of crews for future missions.

Julie K. Poudrier

Kanas' research team included Charles Marmar, Daniel Weiss, and Ellen Grund, all of the University of California, San Francisco, and the Mental Health Service of the San Francisco Department of Veterans Affairs Medical Center; Alan Bostrom, of the University of California, San Francisco; and Vyacheslav Salnitskiy, Vadim Gushin, Olga Kozerenko, and Alexander Sled, all of the Institute for Biomedical Problems, Moscow, Russia. Recent articles describing this research include Kanas, N. et al., "Interpersonal and cultural issues involving crews and ground personnel during shuttle/*Mir* space missions," *Aviat. Space Environ. Med. 71(9)(Suppl)*: A11–16, 2000; and Kanas, N. et al., "Crewmember and ground personnel interactions over time during shuttle/*Mir* space missions," *Aviat. Space Environ. Med.* 72: 453–461, 2001. For additional information on Kanas' research, visit *http://www.kanas1.org.*

Profile: Peggy Whitson

Peggy Whitson looks forward to combining the roles of astronaut and researcher as a member of the fifth crew to inhabit the International Space Station.

"By far, the hardest thing I've had to do in the process of training for this mission is to learn Russian," says Peggy Whitson, who is scheduled to fly to the International Space Station (ISS) with two cosmonauts in April 2002. In addition to learning Russian so that she can communicate with her Russian crewmates, Whitson also had to learn about operating the U.S.–designed life support and control systems on the station and about conducting onboard research. A biochemist who has been performing research for 20 years, Whitson will be conducting her own experiment on crew health aboard the ISS, as well as operating the facilities containing other scientists' experiments. Whitson's research background gives her a unique perspective on her upcoming assignment on the space station.

Whitson's preparation for combining the roles of researcher and astronaut started years before her selection to be part of the fifth crew to inhabit the ISS. She remembers, "I grew up at a time when men were walking on the Moon, and that was pretty impressive. So I think I always wanted to be an astronaut, and science is one way of becoming an astronaut, and obviously I was interested in science." Whitson's formal science studies began at Iowa Wesleyan College, where she graduated with a degree in biology and chemistry. She completed her graduate work at Rice University and then went on to do postdoctoral research at Johnson Space Center (JSC) as a resident associate for the National Research Council. She has been affiliated with NASA ever since.

Working as a researcher at NASA has brought Whitson several opportunities related to science — and to spaceflight. In 1992, she became project scientist for the shuttle/*Mir* program, a position she held until 1995. During this time, her own research in assessing kidney stone risk for astronauts was carried out aboard Russian Space Station *Mir*. From 1995 to 1996, Whitson served as co-chair of the U.S.–Russian Mission Science Working Group, which reviewed plans for and results of research conducted during the shuttle/*Mir* program.

In 1996, Whitson was selected as an astronaut candidate and began two years' worth of astronaut training. "Having worked here [at JSC], I probably had a better feel for what being an astronaut means and what was involved in the training," said Whitson. "I don't think I was too surprised by much. It was fun — a lot of fun." In November 2000, Whitson began training specifically as a crewmember for her stint on the ISS, together with mission commander Valeri Korzun and cosmonaut Sergei Treschev.

Concurrently, Whitson has begun preparation for her own ISS experiment, Renal Stone Risk Assessment. The experiment, a follow-up to research conducted aboard *Mir* and on shuttle missions, is designed to understand and mitigate the risk of astronauts' forming kidney stones. During spaceflight, bones demineralize. Whitson and her co-investigators found that, as a result of the demineralization, more calcium is excreted through the urine and the level of citrate, an inhibitor of stone formation, decreases. These factors increase the risk of forming renal stones during and after spaceflight. On the basis of results from ground-based studies both of subjects who do not form stones and of subjects who were at risk for forming them, the researchers hypothesized that giving potassium citrate to space station crewmembers on a daily basis might decrease their risk of stone formation.

Starting with the third crew to fly on the ISS, crewmembers will take either potassium citrate or a placebo on a daily basis. Crewmembers will collect urine samples for a 24-hour period three times during their stay aboard the station. Because diet also influences the risk of kidney stones, crewmembers' diets will be monitored as well. After she returns to Earth, Whitson and her research team will look at specific urinary components to calculate the risk of stone formation and determine if potassium citrate can inhibit stone formation.

Having been a researcher and an astronaut trainee has allowed Whitson to see the preparation of an ISS mission from a viewpoint that few people have. "Because I worked here at NASA, I saw from the science side what astronauts had to put up with in order to carry out research during flight, and now I see it also from the crewmember side, which is a huge asset," she says. "I think most investigators underestimate how difficult it is to conduct experiments in space."

Whitson is excited at the opportunity to carry out both of her roles on the ISS. She notes, "The fact that I am still conducting research is important to me because I think the research we're doing can have some real benefit for keeping astronauts in space longer and reducing their health risk while they're there."

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